# SORMA WEST 2008

2008 Symposium on Radiation Measurements and Applications

June 2-5, 2008 Berkeley, California, USA

## Oral Program as of May 27, 2008

We invite you to Berkeley for the first West Coast meeting of the Symposium on Radiation Measurements and Applications.

SORMA West 2008 is hosted jointly by the University of California, Berkeley and the Lawrence Berkeley and Lawrence Livermore National Laboratories. It is made possible by the generosity of our agency sponsors and private-sector supporters.

We gratefully acknowledge the cooperation and advice of the original SORMA, now SORMA East, hosted by the University of Michigan and next scheduled for 2010.

Note: the Monday opening plenaries (in International House) and Thursday summary or rapporteur plenaries are described in a different document.

Monday's plenaries will be held at International House, which is also the location of the poster session and reception. The parallel oral sessions Tuesday through Thursday, and the closing plenary, will be in Stanley Hall (rooms 105 and 106) and Bechtel Engineering Center (Sibley Auditorium).

# Table of Contents

# **Thursday, June 5**
## Plan of the Day

Contributed orals in parallel sessions will be given in Sessions AM I and II and PM I. Session PM II will be a plenary session featuring summary or *rapporteur* talks, a good way to catch up on highlights of the parallel sessions.

Lunch (on your own) is 12-2. Those holding a Thursday ticket for an LBNL tour will be guided to the shuttle-bus stop.

Buses back to the Doubletree will begin boarding shortly after the 5 p.m. end of the summary session.

That will conclude SORMA West 2008; we wish you a safe trip to the airport or a pleasant evening in the Bay Area, and encourage you to consider SORMA East 2010 as the venue for your next results.

# Detector Systems

## *Thursday AM I: Stanley 105*

*Chair: Lorenzo Fabris, ORNL*

*Thursday AM I: Stanley 105-1*

**IceCube - a Cube Kilometer Radiation Detector**

*Spencer Klein, Lawrence Berkeley National Laboratory*

IceCube is a neutrino detector now being built at the South Pole. The active volume is 1 km^3 of Antarctic ice at depths from 1450 to 2450 meters below the surface, about 2 km from the Amundsen-Scott South Pole station. Cherenkov radiation from charged particles produced by neutrino interactions in this ice is observed by an array of 4800 Digital Optical Module (DOM) detectors. Each DOM contains a 25-cm photomultiplier tube, high-voltage power supply, digitization electronics, 13 LEDs for calibration, and communication system to transmit digital data to the surface. All data are sent to the surface; a trigger there selects time-windows containing interesting events. Data from this trigger is recorded at the South Pole, and a fraction is transmitted north via satellite. The harsh weather (including temperatures below -55 degrees C) and difficult logistics require significant attention to survivability, reliability, and the simplest possible deployment. IceCube construction began in 2005, and the detector is now 50% complete. IceCube can detect neutrinos with energies from about 100 GeV up to 100 EeV, and can separate electron, muon and tau neutrinos on the basis of their distinctive interaction topologies. Muon neutrinos produce muons, which leave long (1 km for a 500 GeV muon), tracks in the detector, while electron neutrinos produce compact electromagnetic showers. At energies above about 1 PeV, tau neutrinos can produce a spectacular “double-bang” topology -- one energy cluster where the neutrino interacts in the detector, a minimum ionizing tau track, and a second energy cluster when the tau decays, several hundred meters from the first light. For high-energy muon tracks, an angular resolution of about 1 degree is possible. Because neutrino interactions are so rare (10,000 atmospheric neutrinos/year in the complete detector), background rejection is a major challenge. The down-going cosmic-ray muon rate is about 500,000 times higher than the neutrino rate; selecting signal events requires complex background rejection techniques. Neutrino reconstruction also requires robust calibrations. Much effort has gone into understanding the optical properties of the ice that makes up IceCube. The absorption and scattering lengths have been measured as a function of depth and photon wavelength. The DOM timing calibration system maintains relative timing to better than 3 nsec, across the entire array. IceTop, a 160-tank surface array detects cosmic-ray air showers with energies above 300 TeV. It is used to study the cosmic-ray energy spectrum and nuclear composition, for IceCube directional calibration, and as a veto for events originating in the atmosphere. Each tank contains two DOMs frozen into a block of clear ice. After reviewing the physics goals of IceCube, I will discuss the detector in detail, with emphasis on how it can detect and reconstruct neutrino interactions. I will also present some initial results on atmospheric neutrinos, searches for extra-terrestrial neutrinos, and cosmic-ray physics.

*Thursday AM I: Stanley 105-2*

**Multi-Frame High Resolution Imaging System for Time-Resolved Fast-Neutron Radiography**

*Volker Dangendorf, Physikalisch-Technische Bundesanstalt*

In recent years, significant progress in fast-neutron based interrogation techniques for air luggage and palletized cargo has been achieved by introducing a new method of multi-frame high speed imaging, that incorporates ultra-fast exposure timing on the nanosecond time scale. The method utilizes pulsed broad-energy (1 - 10 MeV) neutron beams and energy selective fast-neutron imaging techniques. One of the detection methods which we investigated in recent years will be presented here. It is based on a modified (but, in principle, commercially available) high-speed camera systems with segmented, independently gateable image intensifiers and a very fast optical booster. The booster provides sufficient light even from very faint light sources such as ultra-fast plastic and liquid scintillators for the high-speed camera system. Utilizing the Time-of-Flight (TOF-) method, the detector is able to simultaneously take images of up to 8 images, each at a different neutron energy. Additionally also the gamma flash, preceding the neutrons in the TOF spectrum, can be included in the image series. Thus, also combined neutron / gamma interrogation of objects becomes feasible which allows to combine the low-Z element sensitivity of the neutron resonance method with the high-Z materials detection capability of gamma radiography. PS: The subcategories in the selection box above are not properly aligned to the main categories. The preferred subc are: neutron radiography and/or fast neutron detection and spectroscopy

*Thursday AM I: Stanley 105-3*

**Development of a Fast-Neutron Detector with Silicon Photomultiplier Readout**

*Raffaele Bencardino, CSIRO Minerals*
*John E. Eberhardt (CSIRO Minerals, Private Mail Bag 5, Menai NSW 2234 Australia)*

CSIRO has developed a fast-neutron/gamma-ray radiography (FNGR) technique for the rapid imaging (including composition) of air freight. Whilst the output of the Co-60 gamma-ray source used in the scanner is constant, the output of the 14 MeV DT neutron generator varies and needs to be monitored if high quality images are to be obtained. A full-scale system operated at Brisbane Airport, Australia used a Thermo A-711 generator (producing up to 1.0e10 n/s) and a neutron monitor comprising a fast scintillator read out using a photodiode. To avoid radiation damage to the photodiode, the monitor could not be operated close to the generator, which limited the statistical precision of the flux measurements. A new monitor detector was developed comprising an Eljen EJ-204 plastic fast scintillator block coupled to a Hamamatsu S10362-11-100C 1 mm2 silicon photomultiplier (SiPM) via a 1.5 m length of Kuraray Y11 wavelength shifting (WLS) plastic fibre. The paper discusses the optimisation of the optical design and the implementation of a gain-stabilisation thermally-controlled bias circuit. Count rates and pulse height spectra are compared for the old and the new neutron monitor detectors. The new arrangement allows the scintillator block to be operated close to the source, significantly improving neutron count rates. Using a Thermo A-325 generator (producing up to 6.0e7 n/s), count-rates over 20,000 cps were measured with a small scintillator placed close to the neutron emission point. The new detector design is ideal for measuring rapid variations in flux in a high radiation environment.

*Thursday AM I:  Stanley 105-4*

**Advanced Compact HPC System with Switched Architectures for Large High-Performance Detectors**

*V.I. Vinogradov, Institute for Nuclear Research, Russian Academy of Sciences*

New Electronics, Compact Computer Systems and Communication are moving to Integrated Switched System-Network Architecture and giga-speed component interconnects. A tradition parallel bus based system architectures (VME/VXI bus, cPCI/PXI) are not perspective for new generation high-speed low-power Processors. Advanced high-speed interconnect and HPC systems for high-speed data sources are required. Fundamentals in new generation system architecture development are to decide of gigabit limit speed between system components at low-level signals, low power multi-core processors with new serial switched high-speed interface chips and high-modular structure on all levels of both system and network interconnects. Advanced modular system components and development approaches based on advanced international standards are described and discussed, including new high-speed serial interconnects, module structures, new connectors, interactions of processor cores in distributed compact nodes and general network architecture and topology. Perspective switched tendencies are especially effective for high-performance large detectors, future data acquisition and image processing systems.

Thursday AM I:  Stanley 105-5

**Analysis of the signal and Noise Characteristics Induced By Unattenuated X-Rays from a Scintillator in Indirect-Detection CMOS Photodiode Array Detectors**

*Ho Kyung Kim, School of Mechanical Engineering, Pusan National University*
*Seung Man Yun (presenting), Chang Hwy Lim, Min Kook Cho (School of Mechanical Engineering, Pusan National University); Thorsten Graeve (Rad-icon Imaging Corp.)*

For an indirect-detection CMOS photodiode array detector, the signal due to direct x-ray absorption and the related quantum noise have been analyzed. The direct x-rays are those that are unattenuated from a scintillator and that directly interact with a photodiode array. In order to isolate the signal response induced by direct x-ray absorption, we inserted a sheet of light absorbing blackout paper between the scintillator and the photodiode array. The characteristics have been analyzed in terms of MTF (modulation-transfer function) and NPS (noise-power spectrum). The detailed results will be addressed. This study will provide a good accounting of the contribution of the unattenuated x-rays in the image quality.

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (Grant No. R01-2006-000-10233-0).

# Novel Radiation Sources for Security and Research

## *Thursday AM I: Bechtel*

*Chair: Arlyn Antolak, Sandia National Laboratory*

*Thursday AM I: Bechtel-1*

**Laser-based, Ultrabright Gamma-Ray Sources: Nuclear Photo-Science and Applications**

*C. P. J. Barty, Lawrence Livermore National Laboratory*
*S. Anderson, A. Bayramian, B Berry, S. Betts, J. Dawson, C. Ebbers, G. Anderson, D. Gibson, C. Hagmann, J. Hall, J. Heebner, M. Johnson, H. Phan, J. Pruet, V. Seminov, M. Shverdin, A. Sridharan, A. Tremaine, J. Hernandez, M. Messerly, P. Pax, F.V. Hartemann, D. McNabb, C. Siders (LLNL, P.O Box 808, Livermore, CA 94551)*

We review the construction of LLNL's novel, laser-based, tunable, monochromatic gamma-ray source. Beam-like gamma-ray (>1 MeV) output with peak pulse brightness more than 15 orders beyond the current synchrotron state of the art are possible. Mono-energetic gamma-rays may be used to efficiently excite nuclear resonance fluorescence and in the process enable new methods for isotope-specific detection and imaging well shielded materials. Application of these sources and techniques to homeland security and nuclear non-proliferation will be reviewed.

*Thursday AM I: Bechtel-2*

**Pulsed White Neutron Generator for Explosives Detection**

*Michael King, Lawrence Berkeley National Laboratory*
*Gill Miller (Madison, AL); Jani Reijonen Nord Andresen, Frederic Gicquel, Taneli Kavlas, Ka-Ngo Leung, Joe Kwan (LBNL, 1 Cyclotron Road, Berkeley, CA 94720)*

Successful explosive material detection in luggage and similar sized containers is a critical issue in securing the safety of all airlines passengers. Tensor Technology Inc. has recently developed a methodology that will detect explosive compounds with pulsed fast neutron transmission spectroscopy. In this scheme, tritium beams will be used to generate neutrons with a broad energy spectrum as governed by the T(T,2n)4He fission reaction that produces 4-9 MeV neutrons. Lawrence Berkeley National Laboratory (LBNL), in collaboration with Tensor Technology Inc., has designed and fabricated a pulsed white spectrum neutron source for this application. The specifications of the neutron source are demanding and stringent due to the requirements of high yield, fast pulsing, and hard vacuum seal. In a unique co-axial geometry, the ion source uses ten parallel rf induction antenna to externally couple power into the toroidal discharge chamber. There are 20 extraction slits and 3 concentric electrodes to shape and accelerate the ions into a titanium target. Fast neutron pulses are created by using a set of parallel-plate deflectors switching between plus and minus 1500 volts. It is expected to achieve 5 ns neutron pulses at tritium beam energies between 80 - 120 kV. First experimental results will be presented.
This work is being supported by Tensor Technology Inc. under contract number LB05-001379.

*Thursday AM I: Bechtel-3*

**Intensity Modulated Advanced X-Ray Source (IMAXS) for Homeland Security Applications**

*Willem G.J. Langeveld, Rapiscan Laboratories, Inc.*
*William A. Johnson (HESCO/PTSE Inc., 2501 Monarch St., Alameda, CA 94501), Roger D. Owen (HESCO/PTSE Inc., 2501 Monarch St., Alameda, CA 94501), Russell G. Schonberg (Schonberg Research Corporation, P.O. Box S, Los Altos, CA 94023)*

X-ray cargo inspection systems for the detection and verification of threats and contraband must address competing performance requirements. High X-ray intensity is needed to penetrate dense cargo, while low intensity is desirable to minimize the radiation footprint, i.e. the size of the controlled area, required shielding and the dose to personnel. We report here on a collaborative effort between HESCO/PTSE Inc., Schonberg Research Corporation and Rapiscan Laboratories, Inc. to build an Intensity Modulated Advanced X-ray Source (IMAXS) that allows such cargo inspection systems to achieve up to 2 inches greater penetration capability, while on average producing the same or smaller radiation footprint as present fixed-intensity sources. Alternatively, the new design can be used to obtain the same penetration capability as with conventional sources, but reducing the radiation footprint by about a factor of three. The key idea is to anticipate the needed intensity for each x-ray pulse by evaluating signal strength in the cargo inspection system detector array for the previous pulse. IMAXS requirements therefore include a linac-based x-ray source capable of changing intensity from one pulse to the next by electronic signal, as well as electronics inside the cargo inspection system detector array determining the required source intensity for the next pulse. The project also aims to significantly reduce the overall size and weight of the IMAXS linear accelerator system and its shielding, as compared to comparable conventional sources. We will investigate the comparative feasibility and technical merits of S-band (2998 MHz) and X-band (9303 MHz) linac designs for the IMAXS.
This project is funded under an SBIR award from DHS/DNDO.

*Thursday AM I: Bechtel-4*

**Pulsed Neutron Facility for Research in Illicit Trafficking and Nuclear Safeguards**

*Bent Pedersen, Institute for the Protection and Security of the Citizen (IPSC)*
*J-M. Crochemore (IPSC), A. Favalli (IPSC), H-C. Mehner (IPSC)*

The Joint Research Centre has taken into operation a new experimental device designed for research in the fields of nuclear safeguards and illicit trafficking. The research projects currently undertaken include detection of shielded contraband materials, and mass determination of small fissile materials in shielded containers. The device, called the Pulsed Neutron Interrogation Test Assembly (PUNITA), incorporates a pulsed 14-MeV neutron generator and a large graphite mantle surrounding a sample cavity. The sealed (D, T) neutron generator emits neutrons in 5-microsecond bursts. After a slowing-down time of about 300 microseconds, an average thermal neutron lifetime of about one millisecond is achieved in the graphite moderator and the sample cavity. By pulsing the neutron generator with a frequency in the range of 10 to 150 Hz, a sample may be

interrogated first by fast neutrons only and a few hundred micro-seconds later by a pure thermal neutron flux. For the detection of materials such as explosives the device employs gamma detectors for characteristic prompt gamma rays from inelastic scattering, by fast neutrons, and from thermal neutron capture. The gamma detectors include HPGe detectors and scintillation detectors based on the Lanthanum Bromide crystal. This new scintillation detector is particularly suited for the detection of activation gamma rays in the MeV range. For the purpose of fissile material assay (nuclear safeguards) the PUNITA device employs about hundred 3-He proportional counters located on the outside of the graphite mantle and embedded in cadmium covered polyethylene modules. The paper reports about the design and characterization of the new research facility as well as the different experimental configurations employed for the research activities in the fields of illicit trafficking and nuclear safeguards. The paper also presents and discusses the results obtained so far.

*Thursday AM I: Bechtel-5*

**Development of New X-ray Source based on Carbon Nanotube Field Emission and Application to the Non Destructive Imaging Technology**

*Jong Uk Kim, Korea Electrotechnology Research Institute (KERI)*
*Hae Young Choi, KERI*

In the present work, a new concept for an x-ray source was developed. The conventional thermionic tungsten filament tube is commonly available in various fields of application, such as, medical diagnostic and therapy system, microwave amplifier, and non-destructive testing (NDT) technology and so on. However, it has intrinsic inevitable problems such as high power consumption, very low x-ray efficiency and out-gassing problems and so on. Therefore, in the present study a new carbon nanotube (CNT) based x-ray source was developed as a substitute for the conventional one. The new x-ray source is consisted of three major parts (i.e., triode structures), for example, the CNT electron field emitter was employed as a cathode, a very thin metal mesh as a grid to extract electrons from the CNTs and finally molybdenum embedded copper target as an anode to accelerate electrons. A supplementary electrostatic double focusing lens was employed in the tube to focus electron beam on the anode target. Detailed description of the tube structure as well as electron beam characteristics were presented in the study. In addition, preliminary x-ray images obtained by using the CNT x-ray tube were also presented in the study.

## Imaging Technology and Special Applications

### *Thursday AM II: Stanley 105*

*Chair: Alan Owens, European Space Agency*

*Thursday AM II: Stanley 105-1*

**Overview of the Nuclear Compton Telescope**

*Eric Bellm, UC Berkeley*

*Steven Boggs, presenter*

*Eric C. Bellm, Jason D. Bowen, Daniel Perez-Becker, Cornelia B. Wunderer, Andreas Zoglauer (University of California Space Sciences Laboratory, Berkeley, CA); Mark Amman (Lawrence Berkeley National Laboratory, Berkeley, CA); Chih-Hsun Lin (National Space Organization (NSPO), Taiwan), Mark E. Bandstra (University of California Space Sciences Laboratory, Berkeley, CA);Yuan-Hann Chang (National Central University, Taiwan); Paul N. Luke (Lawrence Berkeley National Laboratory, Berkeley, CA), Hsiang-Kuang Chang, Jeng-Lun Chiu, Jau-Shian Liang (National Tsing Hua University, Taiwan); Zong-Kai Liu (National Central University, Taiwan); Alfred Huang (National United University, Taiwan); Pierre Jean (Centre d'Etude Spatiale des Rayonnements (CESR), Toulouse, France)*

The Nuclear Compton Telescope (NCT) is a balloon-borne soft gamma ray (0.2 MeV-10 MeV) telescope designed to study astrophysical sources of nuclear line emission and polarization. A prototype instrument was successfully launched from Fort Sumner, New Mexico on June 1, 2005. The NCT prototype consisted of two 3D position sensitive high-purity germanium strip detectors (GeDs) fabricated with amorphous Ge contacts. We are currently working toward two balloon flights: another conventional balloon flight from Fort Sumner, New Mexico in September 2008, and a long-duration balloon flight (LDBF) from Alice Springs, Australia in December 2009. The NCT instrument is being upgraded to include all twelve planned GeDs. The electronics for all twelve detectors have been redesigned for smaller size, lower power consumption, and lower noise, and are now being fabricated and tested. Here we present our current progress in preparing for the flights and discuss sensitivity and performance of the instrument.

The NCT project is funded by NASA under Grant #NNG04WC38G for the NCT-US team and by the National Space Organization (NSPO) in Taiwan under Grant 96-NSPO(B)-SP-FA04-01 for the NCT-Taiwan team.

*Thursday AM II: Stanley 105-2*

**The Gamma-Ray Imaging Mission GRI**

*Cornelia Wunderer, Space Sciences Laboratory, UC Berkeley*

Observations of the gamma-ray sky reveal the most powerful sources and the most violent events in the Universe. While at lower wavebands the observed emission is generally dominated by thermal processes, the gamma-ray sky provides us with a view on the non-thermal Universe. Here particles are accelerated to extreme relativistic energies by mechanisms which are still poorly understood, and nuclear reactions are synthesizing the basic constituents of our world. Cosmic accelerators and cosmic explosions are major science themes that are addressed in the gamma-ray regime. ESA's INTEGRAL

observatory currently provides the astronomical community with a unique tool to investigate the sky up to MeV energies and hundreds of sources, new classes of objects, extraordinary views of antimatter annihilation in our Galaxy, and fingerprints of recent nucleosynthesis processes have been discovered. NASA's GLAST mission will similarly take the next step in surveying the high-energy (~GeV) sky, and NuSTAR will pioneer focusing observations at hard X-ray energies (to ~80 keV). There will be clearly a growing need to perform deeper, more focused investigations of gamma-ray sources in the 100-keV to MeV regime. Recent technological advances in the domain of gamma-ray focusing using Laue diffraction and multilayer-coated mirror techniques have paved the way towards a gamma-ray mission, providing major improvements compared to past missions regarding sensitivity and angular resolution. Such a future Gamma-Ray Imager will allow the study of particle acceleration processes and explosion physics in unprecedented detail, providing essential clues on the innermost nature of the most violent and most energetic processes in the Universe.

*Thursday AM II: Stanley 105-3*

**Modelling an Energy-Dispersive X-ray Diffraction System for Drug Detection**

*Silvia Pani, School of Medicine and Dentistry-Queen Mary Univ of London/Barts and The London NHS Trust, London,UK*

*Emily Cook (Department of Medical Physics and Bioengineering, University College London, UK), presenting; Julie Horrocks (School of Medicine and Dentistry-Queen Mary Univ. of London/Barts and The London NHS Trust,UK); Leah George, Sheila Hardwick (Counter Drug Technologies Team, Home Office Scientific Development Branch, Sandridge, UK); Robert Speller (Department of Medical Physics and Bioengineering, University College London, UK)*

Purpose: Preliminary studies have shown the effectiveness of energy-dispersive X-ray diffraction in illicit drug detection. Following these results, the possibility of an X-ray diffraction system for concealed drug detection is currently being researched. A simulation program has been developed to evaluate the optimum combination of geometrical parameters, beam spectrum and detector. Method: A modelling code has been written in IDL. The model is based on a system consisting of a polychromatic X-ray source, a primary beam collimator, a diffraction collimator at a fixed angle and a spectroscopic detector. The program calculates the angular resolution of the system from the geometrical parameters: the collimator angle, the distances between the elements, the apertures of the collimators, the source size and intensity profile and the sample thickness. Several layers of different materials can be included in the model. The input data are diffraction patterns produced with a commercial, high-resolution diffractometer. The data are convolved with the energy resolution of the detector (typical values for HPGe and CZT have been applied) and by the calculated angular resolution of the system. The broadening of the angular resolution with increasing momentum transfer is taken into account, as well as sample self-attenuation. Finally, the diffraction pattern is weighted by the X-ray tube spectrum. Poisson statistical fluctuations are introduced for developing and validating the material identification protocol. Results: The influence of different parameters on diffraction patterns has been assessed. Comparison with

experimental data for reference materials shows a good agreement for both peak width and peak height.

*Thursday AM II: Stanley 105-4*

**Observation of the n(3He,t)p Reaction by Detection of Far-Ultraviolet Radiation**

*Charles W. Clark, National Institute of Standards and Technology*

*Alan K. Thompson (National Institute of Standards and Technology); John W. Cooper, Michael A. Coplan, Patrick Hughes (University of Maryland); Robert E. Vest (National Institute of Standards and Technology)*

We have detected Lyman alpha radiation as a product of the n(3He,t)p nuclear reaction occurring in a cell of 3He gas. The predominant source of this radiation appears to be decay of the 2p state of tritium produced by charge transfer and excitation collisions with the background 3He gas. Since the speed of the tritons and protons produced in the nuclear reaction is comparable to the speeds of the electrons in the helium atom, the cross sections for such collisions are relatively large. Our experiments use a gas cell and a filtered photomultipler package, mounted on a cold neutron beamline at the NIST Center for Neutron Research. Under the experimental conditions reported here we find yields of tens of Lyman alpha photons for every neutron reaction. These results suggest a method of cold neutron detection that is complementary to existing technologies that use proportional counters. In particular, this approach may provide single neutron sensitivity with wide dynamic range capability, and a class of neutron detectors that are compact and operate at relatively low voltages.

*Thursday AM II: Stanley 105-5*

**Withdrawn**

# Electronics

## *Thursday AM II: Bechtel*

*Chair: Stuart Kleinfelder, Univ. of California, Irvine*

*Thursday AM II: Bechtel-1*

**Fast Self Triggered Multi Channel Readout ASIC for Time- and Energy Measurement**

*Michael Ritzert, University of Heidelberg*
*Peter Fischer (University of Heidelberg), Ivan Peric (University of Heidelberg), Martin Koniczek (University of Michigan)*

We present a 16 channel self triggered readout chip for simultaneous time and energy measurement, suitable for a wide range of applications. All circuit elements required for detector readout are integrated on the chip. A fast, low-noise discriminator detects hits at the differential inputs. The events are time stamped with an electronic resolution of 15ps (single channel rms). The timing range is virtually infinite by means of a coarse counter and an overflow indicator. In parallel to the time stamping of the discriminated input signal, the analog input is integrated during a programmable time window and digitized with 8 bit integral resolution. Readout is achieved through a simple serial protocol. Several chips can be synchronized by means of a built in PLL circuit locking to a common reference clock. The 3x3mm2 chip has been fabricated in 0.18um technology, employing a differential logic for all crucial parts. Possible applications of this ASIC are in high energy physics experiments, medical imaging, range finding, georadar and other fields.

*Thursday AM II: Bechtel-2*

**High Speed Multichannel Charge Sensitive Data Acquisition System with Self Triggered Event Timing**

*Anton S. Tremsin, Space Sciences Laboratory, UC Berkeley*
*Oswald H.W. Siegmund, John V. Vallerga (Space Sciences Laboratory, UC Berkeley)*

A number of modern experiments require simultaneous measurement of charges on multiple channels. The event rates exceeding MHz levels and requirement of charge detection with accuracy of 100-1000 electrons rms require adequate data processing electronics. One of the widely used data processing scheme relies on application specific integrated circuits enabling multichannel analog peak detection asserted by an external trigger followed by a serial/sparsified readout. Although that configuration minimizes the back end electronics, its counting rate capability is limited by the speed of the serial readout. The recent advances in analog to digital converters and FPGA devices enable fully parallel high speed multichannel data processing with digital peak detection enhanced by the finite impulse response filtering. Not only can the accurate charge values be obtained at high event rates, but the timing of the event on each channel can also be determined with high accuracy. We present the concept and first experimental tests of fully parallel 128-channel charge sensitive data processing electronics capable of measuring charges with accuracy of 1000 e- rms. Our system does not require an external trigger and, in addition to charge values, it provides the event timing with an accuracy of

~1.2 ns. One of the possible applications of this system is high resolution position sensitive event counting detectors with microchannel plates combined with cross strip readout. Implementation of fast data acquisition electronics increases the dynamic range of those detectors to multi-MHz level, preserving their unique capability of virtually noiseless detection of both position (with accuracy of 10 um FWHM) and timing (~1.2 ns FWHM) of individual particles, including photons, electrons, ions, neutrals, and neutrons.

*Thursday AM II: Bechtel-3*

**Electronics Development for Fast-Timing PET detectors: The Multi-Threshold Discriminator Time of Flight PET system**

*Jialie Lin, University of Chicago and Enrico Fermi Institute, University of Chicago*
*Octavia Biris (University of Chicago), Chin-Tu Chen (Department of Radiology, University of Chicago), Woon-Seng Choong (Lawrence Berkeley National Laboratory), Henry Frisch (University of Chicago and Enrico Fermi Institute, University of Chicago), Chien-Min Kao Chen (Department of Radiology, University of Chicago), William W. Moses (Lawrence Berkeley National Laboratory), Fukun Tang (Univ. of Chicago), Qingguo Xie (Department of Radiology, Univ.of Chicago), Lin Zhou (Univ. of Chicago)*

We present the status of development of an all-digital Positron Emission Tomography system designed to have time-of-flight resolution of less than or equal to 100 picoseconds. The timing resolution we strive for will much improve the quality of imaging obtained in radiology and medical physics fields [1]. The test setup is composed of a 1-cm diameter Fluorine-18 source giving two back-to-back gamma rays, which impinge on a pair of detector modules, each consisting of a 6.25 x 6.25 x 3 mm^3 LSO scintillator that is covered by Teflon on five sides and coupled to a Hamamatsu R9800 PMT. The outputs of each detector were read into a 40-GHz sampling Tektronix oscilloscope to form a library of pulses. Using a constant fraction discriminator, these pulses have a measured coincidence timing resolution of ~300 ps fwhm and a 2~3 ns rise time [2]; studies are underway to understand the underlying physical effects contributing to the timing resolution. By having a digitized pulse train available, we can test different algorithms to extract timing estimators, but the event rate provided by oscilloscopes is too low to be practical for what we encounter in PET. We are therefore developing electronics that are compatible with PET requirements. The architecture of the electronics system consists first of a multi-threshold discriminator, using Analog Devices' Ultrafast SiGe Voltage Comparators ADCMP582 [3]. The output from the comparators will then feed into a board with the CERN High Performance Time to Digital Converter [4], which further feeds into a Xilinx Spartan FPGA, then a Digital IO board to allow input into a

PC. In order to optimize the number and setting of the thresholds the pulses collected were fed into a simulation of the electronics and analysis [2]. In light of the preliminary simulation results, our discriminator will have eight thresholds, to allow for a broad range of input PET pulse-types and to compare with the simulation. We will present results on the analysis of the timing characteristics of the pulse as well as the construction and performance of the multi-level timing discriminator.

[1] W. Moses. Time of Flight PET revisited, IEEE Trans. on Nucl. Sci. 50 (2003) 1325.
[2] Q. Xie, C. Kao, X. Wang, N. Guo, C. Zhu, H. Frisch, W. Moses, C. Chen. Potential advantages of digitally sampling scintillation pulses in timing determination in PET. IEEE NSS `07 CR. 6 (2007) 4271.
[3] http://www.analog.com/UploadedFiles/Data_Sheets/ADCMP580_581_582.pdf [4] M. Mota, J. Christiansen, S. Debieux, V. Ryjov, P. Moreira, A. Marchioro. A flexible multi-channel high-resolution time-to-digital converter ASIC. IEEE NSS `00 CR. 2 (2000) 9/155.

*Thursday AM II: Bechtel-4*

**High Sensitivity Readout and Data Processing for Environmental Spectral Radiation Measurements**

*Vladimir Popov, Jefferson Laboratory*

We have developed a new version of high sensitivity electronics front end and analog signal processing for use with high pressure ionization chambers in environmental radiation measurements. The readout circuit provides low noise signal readout from individual events of gas ionization. Readout electronics is connected to the analog-to-digital converter providing continuous high rate data sampling. The data processing algorithm allows noise rejection and extraction of pulse shape and amplitude information related to the ionization loss in the gas for each ionization event. The output of the detector could be presented in a traditional way as the accumulated ionization charge per unit time, and as a signal amplitude spectroscopic distribution. Results of the initial evaluation are presented. These results were obtained using the designed electronics connected to the RSS-1013 Reuter-Stokes high pressure ionization chamber filled with Ar at 25 atm. The HPIC detector was tested using cosmic radiation and several external radiation sources. Combined measurements of total ionization and ionization spectrum in the detector provide a new type of powerful instrument capable of better separation between the natural background radiation and the radiation form external sources, as well as the improved low energy gamma radiation detection.

*Thursday AM II: Bechtel-5*

**Radiation Tolerance of an Analog LSI Developed for X-ray CCD Camera Readout System Onboard an Astronomical Satellite**

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We present the results of radiation damage experiment of an analog Application Specific Integrated Circuit (ASIC) developed aiming at the use in a readout system of X-ray CCD camera. Conventional X-ray CCD cameras onboard X-ray astronomical satellites have achieved fano-limited energy resolution and superior spatial resolution with X-ray mirrors. The only weakness of the X-ray CCDs is relatively inferior readout time, which causes pile-up of X-ray events and subsequent wrong measurement of the X-ray photon energy. The most reliable and direct method to improve timing resolution without declining other performances is to increase the number of readout nodes of X-ray CCDs. However, this requires the larger size and higher power consumption of the data acquisition systems. Then we are developing an ASIC and subsequent electronics, with which we are able to achieve very high readout rate of approximately 1Mpixels/sec, much faster than conventional frame-transfer type CCD systems in orbit. Our ASIC consists of four identical sub-circuits that simultaneously process X-ray events. Each sub-circuit is composed of pre-amplifier, 5-bit DAC, and delta-sigma type AD converter. It has been fabricated with Taiwan Semiconductor Manufacturing Company (TSMC) 0.35-micron CMOS process and then 3mm square bare chip is Quad Flat Pack (QFP) packaged. We introduced delta-sigma converter into the readout system of X-ray CCD for the first time. It is characterized with high-resolution using relatively simple circuit and its noise-shaping architecture drives white noise away to higher frequency than that of the signal band. The output digitized signals are decimation-filtered in a subsequent FPGA. Our ASIC has realized rather low power consumption down to the order of 100mW per chip, we are able to load many chips to a satellite and hence high timing performance could be possible even using X-ray CCDs with many readout nodes. We have also succeeded to readout with high speed of 625kpixels/sec and with low noise of less than six electrons, which is comparable with existing X-ray CCDs in orbit. The effective energy range reaches up to approximately 40 keV, which is sufficiently high for use in X-ray astronomy. Radiation tolerance of the ASIC is one of the critical issues to put it in orbit. In the low-earth orbit, the ASICs suffer low-energy solar protons when the satellite goes through South Atlantic Anomaly (SAA). Hence we conducted the radiation damage test with 200MeV proton beam utilizing HIMAC (Heavy Ion Magnetic Accelerator in Chiba) in Japan. There was no significant degradation the noise performance and linearity until the absorbed dose amounts more than 14krad, which corresponds to approximately 14 years endurance in the low-earth orbit. When the absorbed dose exceeded 14krad, the noise performance and linearity suddenly degraded for every channel but there was no significant increase of the current. Typical mission time of X-ray astronomical satellite is less than 10 years, hence we proved that our ASIC has sufficient radiation tolerance for use in the low-earth orbit.

## Radiation Measurements in Physics

### *Thursday PM I: Stanley 105*

*Chair: Yuen-Dat Chan, LBNL*

*Thursday PM I: Stanley 105-1*

**MAJORANA: An Ultra-Low Background Enriched-Germanium Detector Array for Fundamental Physics Measurements**

*Jason Detwiler, Lawrence Berkeley National Laboratory*

For decades, germanium detectors have played a central role in fundamental physics measurements, for example searches for neutrinoless double-beta decay (0nbb). Detecting this phenomenon would establish the Majorana nature of the neutrino and simultaneously give a measure of the absolute neutrino mass scale. The MAJORANA collaboration aims to perform such a search by fielding arrays of HPGe detectors mounted in ultra-clean electroformed-copper cryostats located deep underground. Recent advances in HPGe detector technology, in particular highly-segmented detectors and point-contact detectors, show great promise for identifying and reducing backgrounds to the 0nbb signal, which should result in improved sensitivity over previous generation experiments. The MAJORANA Demonstrator R&D program will field three ~20 kg modules of segmented and point-contact detectors, of which 30 kg will be enriched to 86% in 76Ge. I will present recent progress in this R&D effort, and discuss its physics reach. I will also contrast MAJORANA's "clean cryostat" approach with the "active cryogen" approach currently being pursued by the GERDA collaboration in Europe, and discuss the future of 0nbb experiments in 76Ge.

*Thursday PM I: Stanley 105-2*

**NA62 RICH: Test Beam Results**

*Antonino Sergi, INFN - Perugia, Italy*

NA62 experiment at CERN, aimed to measure K -> pi nu nubar branching fraction (O(10^-11)), relies on a gas based RICH detector for pion/muon separation and L0 trigger. The experimental requirements on this detector are mainly a time resolution of 100ps and a muon rejection better than 10^-3 in the momentum range 15-35GeV. A first prototype of such a detector has been built and tested in October 2007: it is a full lenght (18m) Ne filled vessel equipped with a spherical mirror and 96 PMs on its focal plane, 17m upstream. The test has been performed at the CERN SPS on a 200GeV pion beam, mainly as a first check of its time resolution and of the light collection technique; the time resolution has been found to be about 65ps, and the light collection, i.e. the number of hit PMs, fairly as expected. Other parameters, like cerenkov angle resolution and track angle resolution, even if biased by the low number of PMs, have been tested and found within expectation.

*Thursday PM I: Stanley 105-3*

**Performance of the CREAM-III Calorimeter**

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Cosmic Ray Energetics And Mass (CREAM) is a balloon-borne experiment to directly measure the elemental spectra of protons to iron nuclei with energies up to ~ 10^15 eV. Energies of these cosmic ray particles are measured by an ionization calorimeter comprised of 20 layers of 1 radiation length thick tungsten plates and 20 layers of 0.5 mm diameter scintillating fibers. Each tungsten plate is 500 x 500 x 3.5 mm^3 and the fibers are grouped into fifty 1 cm wide ribbons. The CREAM-III calorimeter was constructed and tested at CERN, the European high energy physics lab, in the H2 beam line of the SPS. Following the CERN test, the calorimeter was integrated into the CREAM-III instrument, and flown successfully in the 3rd flight during the 2007/8 Antarctic campaign. We present performance of the CREAM-III calorimeter in lab and beam tests.

*Thursday PM I: Stanley 105-4*

**New X-ray Detectors for Exotic Atom Research**

*Johann Marton, Stefan Meyer Institute*

Exotic atoms of low Z systems in which the electron is substituted by a hadron like a negatively charged K meson are perfect probes for studying strong interaction at lowest energies using X-ray spectroscopy. New large area X-ray detectors (silicon drift detectors, SDDs) were developed to provide excellent energy resolution as well as timing capability. For the first time large area SDDs were employed to measure the L-lines of kaonic helium at high precision thus succeeding in clarifying a puzzle persisting 30 years since the 70s. An array of about 200 even more sophisticated SDDs (1cm2 SDDs with integrated FET) will be used to perform precision measurements (at the eV level) of kaonic hydrogen and kaonic deuterium (first measurement) at the DAFNE Phi-factory of LNF/Italy. The new X-ray detectors and the performance for precision experiments in the environment of an accelerator will be presented.

*Thursday PM I:  Stanley 105-5*

**Active, Beam-Defining Elements for Synchrotron Beamlines**

*Chris Kenney, Molecular Biology Consortium*
*Jasmine Hasi, presenter*
*A.C. Thompson, C.J. Kenney, E. Westbrook, C. Da Via, S.I. Parker*

Measuring the position of x-ray synchrotron beams is becoming more important as many experiments are using intense focused x-ray beams that are less than 100 by 100 square microns. In addition, many samples are heterogeneous so it is important to know that the beam is stable on a particular part of the sample. For example, protein crystallography experiments are now routinely studying crystals that are less than 30 by 30 by 30 microns cubed. If the beam moves relative to the crystal by more than 10 microns, the data quality is seriously degraded. Relatively inexpensive and simple beamline diagnostic apparatus has the potential to improve the delivery of beams to the samples. Passive beam elements, such as collimating slits made of tungsten, perform the function of blocking part of the beam, but provide no information about the beam. Active beam elements, such as collimating slits made of entirely or partly of silicon diodes, allow continuous recording of the blocked photon intensity, profile, and other parameters. Small real-time changes in beam position or intensity can be easily determined by measuring the current from these devices. They can also serve as a beam profile monitor, if the blade is scanned across the beam. Active edges are critical to most of these designs as the absence of insensitive edges greatly enhances the usefulness of such devices. Our group is developing a variety of diagnostic instruments for synchrotron beam lines. Results with collimating pinholes and slits made of silicon diodes will be presented.

## Medical Applications

### *Thursday PM I: Bechtel*

*Chair: David Wehe, Univ. of Michigan*

*Thursday PM I: Bechtel-1*

**Recent Results from Axial 3-D PET Modules with Long LYSO Crystals, Wave Length Shifter Strips and SiPM Readout**

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We describe a novel concept to extract the axial coordinate from a matrix of long axially oriented crystals, which is based on wavelength shifting (WLS) plastic strips. The method allows building compact 3-D axial gamma detector modules for PET scanners with excellent 3-dimensional spatial, timing and energy resolution while keeping the number of readout channels reasonably low. One module consists of a stack of 100 mm long LYSO scintillation crystals interleaved with arrays of WLS strips which allow the determination of the axial coordinate. To detect the light from the Crystals and the WLS strips Silicon Photomultipliers (SiPM) are employed. A voxel resolution of about 8 mm3 is expected. The performance of the concept has been demonstrated with a test set-up consisting of two long LYSO crystals and two WLS strips read out by SiPMs. Results obtained with the test set-up, demonstrating spatial, energy and timing resolution, will be summarized. Recent progress in building a demonstrator PET scanner prototype is reported.

*Thursday PM I: Bechtel-2*

**Single crystal film scintillators for X-ray imaging applications with micrometer resolution**

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X-ray detector systems are powerful tools which provide volumetric data of samples during a non-destructive examination for biology, medicine and material sciences. The detector able to provide sub-micrometer spatial resolution consists of a scintillator, light microscopy optics and a cooled charged-coupled device (CCD). The scintillator converts the X-ray into a visible light image which is projected onto the CCD by the light optics. Single Crystal Film (SCF) scintillator, grown by liquid phase epitaxy (LPE) from 1micron to 30micron thick, used for high resolution imaging suffers of low efficiency (2% at 50keV) owing to its few micron thickness. The detective quantum efficiency (DQE) is then mainly limited by the low absorption of X-rays and the light yield in the thin layer of scintillator. Performances, i.e absorption, light yield, afterglow, temperature effect and radiation hardness, of the operational system based on YAG:Ce, LAG:Eu and GGG:Eu scintillators[1] will be presented and compared to new LSO:Tb scintillators

developed in the European project, SCINTAX[2]. A new concept to improve the efficiency of detection in the 20-40keV energy range with 1micron spatial resolution will be presented. This concept based on multilayer scintillator can be produced by LPE process. An approach of this concept will be illustrated with X-ray images and will demonstrate the absorption efficiency improvement of the X-ray detector. The expected improvement is 8 times better than the current LAG scintillators. Keywords: X-ray imaging, scintillator, liquid phase epitaxy, microscopy, microtomography, synchrotron radiation.
The project SCINTAX is funded by the European Community (STRP 033 427, FP6)
[1] T. Martin and A. Koch, J. Synchrotron Rad. (2006) 13, 180-194
[2] K. Dupre, M. Couchaud, T. Martin, A. Rack, German Patent Application no. 10 2007 054 700.7 (2007).

*Thursday PM I: Bechtel-3*

**Distributed Phantoms in Planar Coded Aperture Nuclear Medicine Imaging: Experimental Results**

*David M. Starfield, University of the Witwatersrand, Johannesburg*
*David M. Rubin, Tshilidzi Marwala (University of the Witwatersrand); Rex J. Keddy*

Acquisition of images in nuclear medicine typically requires the use of a collimator. Coded apertures are an alternative to collimators, and under specific conditions can augment the signal-to-noise-ratio (SNR) of the system. However, the near-field geometry of nuclear medicine results in the presence of artifacts, and the SNR decreases further for distributed sources. The paper aims to provide a clear indication of the applicability of simple coded aperture acquisition for the near-field distributed sources of nuclear medicine. With respect to the low-energy-high-resolution (LEHR) parallel-hole collimator, septa size remains fixed. Resolution cannot be increased without a decrease in the open fraction of the collimator. Coded apertures have multiple holes that can be designed for optimal performance with a specific gamma camera, such that both the open fraction of the material and the field-of-view are maintained. Neither zero-order nor first-order artifact correction is implemented. Second-order artifact reduction is applied to all images. An anti-symmetric, self-supporting coded aperture is constructed by laser drilling a 1 mm tungsten sheet. A specialized aluminium frame attaches the coded aperture to the Philips Axis gamma camera. Printer cartridges are injected with Technetium-99m to obtain repeatable two-dimensional phantoms of distributed sources. Collimator and coded aperture images are acquired simultaneously. The results presented in the paper show that the coded aperture reconstructions suffer from significant noise. Simple multiplication of the collimator and coded aperture images decreases noise compared to the original coded aperture image, while the resolution advantage over the LEHR collimator image is retained. Use of the current state-of-the-art in coded aperture technology and an existing gamma camera, together with straightforward artifact correction and simple reconstruction techniques, gives coded aperture images that are at least comparable to collimator images. Unlike collimators, the potential exists for design of higher resolution coded aperture systems. The authors believe that the experimental results, which will be presented in the paper, will provide a motivation for both further work on coded apertures and enhanced gamma camera design.

This work was supported by the University of the Witwatersrand, Johannesburg, and by the National Research Foundation of South Africa.

*Thursday PM I: Bechtel-4*

**Characterisation of the Components of a Prototype Scanning Intelligent Imaging System for use in Digital Mammography: The I-ImaS System**

*Colin Esbrand, University College London*

The physical performance characteristics of a scanning system for a prototype digital mammography (DM) unit has been investigated in terms of noise power spectrum (NPS), modulation transfer function (MTF) and detective quantum efficiency (DQE). The I-ImaS system was designed for use in DM implementing the use of CMOS MAPS promoting on-chip intelligence therefore enabling statistical analysis to be achieved in real time for the purpose of feedback during the image acquisition procedure. The focus of the intelligent system is to optimise the diagnostic content of an image implementing a statistical feedback loop where the x-ray beam intensity is modulated based on the nature of the region of tissue being scanned. The system consists of a dual array of CMOS MAPS that have been designed and developed specifically for this project. Twenty 520x40 32 micron pixel sensors are implemented within the system enabling a preliminary image (the scout image) and a diagnostic image to be obtained simultaneously. A 100 um thick thallium doped caesium iodide (CsI:TI) scintillator is used to provide x-ray sensitivity. A set of 10 x-ray attenuating filters are implemented where each one was specifically designed to provide various degrees of beam attenuation depending on the statistical information fed to the modulators. Prior to system characterisation care was first taken to directly determine the linearity of the system. The MTF was determined via the Fourier transform (FT) of an oversampled line spread function (LSF) obtained using the angled slit method according to the technique described by Fujita et al 1992. The MTF was found to be 0.1 at 6 cycles/mm. The 1-D noise power spectrum was estimated using the direct method where a thick slice consisting of 8 lines through the central region of the measured 2-D noise power spectrum was used. The presented noise power spectrum results illustrate the noise power decreases as exposure is increased. The 2-D spectra for all exposure levels investigated exhibit noise structures both on and off the primary frequency axis indicating the presences of periodic noise components; 1-D noise power spectrum estimates were made over a range of 5 exposures and 3 tube voltages where the results show the noise level to be inversely proportional to exposure and tube voltage having minimal effect. The DQE(0) has been measured to be approximately 0.5 at 17keV. These results show that the I-ImaS system noise, spatial resolution and detection efficiency characteristics are comparable to those obtained by current commercially available DM systems. Current work is on the acquisition of preliminary stitched images obtained conventionally and implementing off line intelligence in an attempt to compare the diagnostic content of the image. Simulations are being carried out in order to determine which statistical measure is best suited for implementation into the feedback mechanism. Once complete, the

results will show the potential benefits of implementing artificial intelligence within the data acquisition stage of digital mammography.

*Thursday PM I: Bechtel-5*

**Synchrotron X-ray Fluorescence Computed Tomography Using an Emission Tomography System**

*Ling-Jian Meng, University of Illinois Urbana-Champaign*
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In this paper, we present a feasibility study of using an emission tomography (ET) system for 3-D mapping of trace elements based on x-ray fluorescence induced by synchrotron radiations. Synchrotron radiation based x-ray fluorescence computed tomography (XFCT) allows 3-D mapping of very low contents of trace metals (at the order of picograms) in volumetric samples. XFCT studies are typically performed using a collimated beam of synchrotron X-rays, scanning line-by-line through a volumetric sample in a first-generation tomographic geometry. Fluorescence X-rays that originate from the sub-volume irradiated by the beam are collected with a high-energy resolution, non-imaging spectrometer, yielding the line integrals through the various elemental distributions. After rotating the object through at least 180 degrees, the 3D distribution of trace elements inside the sample can be reconstructed based on the line integrals collected. Although excellent imaging performance has been demonstrated, the line-by-line mechanical scanning normally leads to a very long imaging time. In recent years, substantial efforts have been made to improve the speed of XFCT studies, which is particularly important for potential in vivo imaging applications. In this paper, we proposed an alternative imaging approach that involves a much reduced scanning steps and therefore offers an improved imaging speed. In this approach, we use an optimized single photon emission computed tomography (SPECT) system to detect the fluorescence x-rays. The proposed system consists of a ring of silicon pad detectors that offers both a high spatial resolution and an excellent energy resolution. In order to achieve an adequate detection efficiency for fluorescence x-rays, a specially designed truncated spherical collimator is used. This aperture consists of multiple pinhole or ring-hole openings surrounding the sample, which offers a detection efficiency of around 1% for X-rays originated in the sample. Although the aperture significantly cuts down the sensitivity, it makes up for this loss by (a) reducing the need for translational and rotational movements of the sample and (b) acquiring data that has much a reduced multiplexing. For the same imaging time, it is possible to achieve XFCT images with a substantially improved signal-to-noise ratio (SNR). In this paper, we will present the design of the dedicated XFCT system. Both experimental and Monte Carlo studies will be performed to evaluate the SNR that can be achieved with this system in comparison to those offered by other sampling techniques based on mechanical scanning.

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