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2.1 SCIPP Tracking R&D

SCIPP has been involved in Linear Collider tracking R&D for a number of years, and its work has led to the development of a refined understanding of several generic tracking issues with potential applications for Linear Collider detectors. These include the use of resistive strips and dual-end readout for the determination of the longitudinal coordinate of the charge deposition on narrow electrodes [1] and limitations on silicon microstrip ladder length for precision narrow-strip sensors [2]. These studies are in fact dependent only on the properties of the electrode that collects the signal and propagates it to the readout electronics, and thus are independent of the sensor technology that generates the signals. Thus, this work may have relevance to detection issues across a wide array of fields. Ongoing tracking R&D is focused on the further development of the Long Shaping-Time Front End (LSTFE) microstrip readout ASIC. This properties of this ASIC have been explicitly optimized for the readout of long ladders of silicon strip sensors that are motivated by the need for precise low-mass central tracking for a Linear Collider Detector. With a small and straightforward change to the shaping properties of the ASIC, it could be reoptimized for use for the short strips and high occupancy that would be expected for ILC forward-tracking applications. Similar to most ILC-oriented readout designs, the LSTFE features a long shaping time optimized to reduce voltage-referenced readout noise, as appropriate for narrow-strip, long-ladder applications. Unique to the LSTFE design, however, is the use of time-over-threshold readout to estimate the analog pulse-height generated by through-going subatomic particles. A pule-development and readout simulation developed at SCIPP suggested that the intrinsic statistical fluctuations of the charge-deposition process in 300 m of silicon obviate the need for a precise measurement of deposited charge. A simulation of the centroid-finding (position-resolution) uncertainty provided by time-over-threshold readout showed little degradation relative to that provided by an exact measurement of deposited charge. On the other hand, there are several advantages offered by the use of time-over-threshold readout. It is very simple to implement within a digital back-end to the LSTFEs analog front end (the implementation would be on the same chip as the front-end readout), requiring only a measurement of the number of clock counts that the given channel is over threshold, and then the assembly and transmission of a single data word containing the time of the upward transition, the time over threshold after the transition, and the channel number. This happens in real time and is driven immediately off the chip into the DAQ, eliminating the need for buffering and ADC conversion. In particular, there is no limit to the rate at which particles can be detected other than the return-to-baseline of the analog signal, and so the data-accumulation rate capability of the device is very high. In addition, for forward tracking, for which short strips are envisioned, the shaping time can be shortened significantly. This will further improve the rate capability of the LSTFE readout, making it an excellent choice for the high-occupancy forward region. Figure 1 shows the measured fractional charge uncertainty for the LSTFE prototype ASIC; for depositions expected from minimum-ionizing par-

ticles (1-4 fC) the fractional charge measurement uncertainty is approximately 15%, which is small compared to the intrinsic fluctuations that arise from the deposition process.

References [1] J. K. Carman et al., Longitudinal Resistive Charge Division in Multi-Channel Silicon Strip Sensors, Nulcear Inst. and Methods in Physics Research A579 (2007), pp 595-598. [2] K. Collier et al., Microstrip Electrode Readout Noise for Load-Dominated Long Shaping-Time Systems, Nuclear Inst. and Methods in Physics Research, A729 (2013), pp. 127-132.

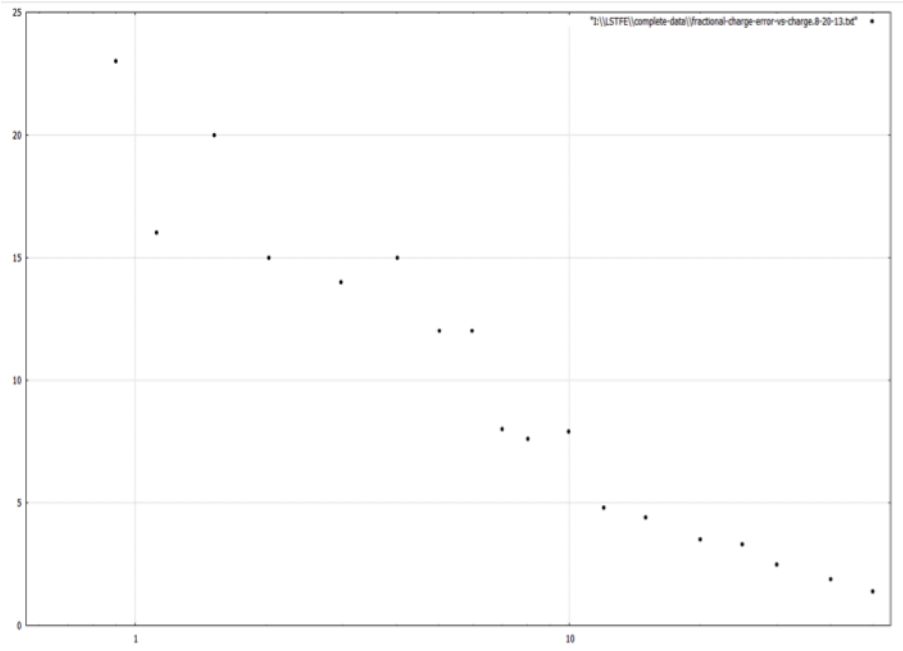

Figure 1: Fractional pulse-height uncertainty (percent) versus injected charge (fC) for the LSTFE front-end ASIC. The development of this ASIC has been done solely at the Santa Cruz Institute for Particle Physics (SCIPP) within the University of California at Santa Cruz, and while slowed significantly due to the loss of support for Linear Collider Detector R&D, continues within SCIPP. Tasks that remain in developing a chip suitable for use in a Linear Collider Detector include the development of the digital back end; significant progress has already been made in defining the architecture of this section of the chip and in implementing this architecture in prototype form on an FPGA. Power cycling (switching the chip into a low-power quiescent mode for most of the 199 ms between beam crossings) also needs to be implemented.

2.2 KPIX

2.2.1 Collaborating Institutions

- SLAC National Accelerator laboratory
- University of California, Davis
- University of California, Santa Cruz
- University of Oregon
- University of New Mexico

2.2.2 Introduction

KPiX is a 1024 channel "System on a Chip" intended for bump bonding to large area Si sensors, enabling low multiple scattering Si strip tracking and high density Particle Flow calorimetry for SiD at the International Linear Collider (ILC).

Each channel consists of a dynamically switchable gain charge amplifier; shaping; threshold discrimination; and 4 sample and hold capacitors and 4 timing registers. The chip permits 4 separate measurements of amplitude and time of threshold crossing during each train, and amplitude digitization and readout during the intertrain period. The dynamic range is from sub minimum ionizing particle (mip) (320 micron silicon) to more than 2000 mip. KPiX also has a calibration system for each channel, servos for leakage compensation, "DC" reset for asynchronous operation for testing with cosmic rays, and polarity inversion for use with GEMs and similar detectors. The noise floor is about 0.15 fC (1,000 electrons), and the maximum signal is 10 pC (utilizing the dynamic range switching). The full dynamic range corresponds to 17 bits.

2.2.3 Recent Milestones

ILC related R&D in the US is largely unfunded and small efforts are being kept alive on the margins. The KPiX R&D is such an example of necessary work for SiD that is marginally alive.

2.2.4 Engineering Challenges

At this time, KPiX is seen as the baseline readout system for the tracker and electromagnetic calorimeter. A stack of 13 EMCal sensors with bump bonded KPiX was assembled for a beam test at SLAC in the summer of 2013. That test discovered that two kinds of crosstalk are significant:

- In-time crosstalk occurs due to parasitic coupling of traces on metal 2 of the sensor to other pixels. The level of crosstalk increases with the size of the signal, and decreases with increased speed of the front end charge amplifier (meaning increased current and power dissipation). A new sensor

design is being developed that uses metal 1 to shield the traces of metal 2, and these ideas will be tested in the next sensor prototype.

- Out-of-time cross talk occurs when many pixels are hit and reset simultaneously. The resets collectively cause other pixels to trigger, and a cascade builds up. This uses up all the KPiX buffers. The root cause of the problem appears to be some internal logic within KPiX that is not current limited, and will require design modification.

A more general issue is that both the EMCal and tracker sensors from Hamamatsu were ordered with Al pads, as it was believed that plating (by the zincate process) a stack of metals culminating with Au would be straightforward. This turns out to be wrong. After many attempts at University of California Davis (UCD) and local industry, IZM has Ar ion etched the pad surfaces and sputtered a base layer, permitting the buildup of a stack that ended with Au, and permitting the attachment with solder bumps that had been placed during KPiX manufacture by TSMC. Testing of these sensors revealed 10% pixel to pixel shorts and some opens of signal traces, that are suspected to be damage caused by the Ar ion etch. Future sensors will be ordered with Au pads. An additional issue is that the Tracker sensor was planned to be wire bonded to its (very thin) cable. The sensor oxide layer is not strong enough to allow wire bonding without damage, and so must be solder bumped. The pad pitch is small, and solder bumping the cable will be challenging. The trouble with the wire bonding to the sensor was unexpected. Another concern is that the current design of KPiX has deadtime after a pixel has accepted a trigger. Only the triggered pixel is affected; all the other pixels are available for signals. This deadtime is different from the usual notion of data acquisition deadtime where the entire detector is unavailable, but the correction to the luminosity integral is easy. Finally, the buffer requirement (4 in the current version of KPiX) is being re-evaluated in SiD simulations. A possible new architecture for KPiX is in early stages of evaluation. A small mechanical engineering effort has started to study the structure of the EMCal. The Sid EMCal has emphasized thin gaps between the tungsten layers to minimize the Moliere radius, and this implies that the structure is connected by columns at the vertices of the sensors. The DBD design shows hexagonal sensors, which indeed are the most efficient way of tiling large areas, but no consideration was given to the edges of these arrays. The engineering work is leading to the realization that it is probably easier and cheaper overall to use two sizes of rectangular sensors, where the two sizes can be selected to tile to the edges of the layers and even tile the endcaps reasonably. Thus it is likely that the next round of EMCal sensor prototypes will be rectangles with square pixels. Tracker sensors are now at IZM for the pad plating and subsequent bonding of KPiX; they will then go to UCD for cable attachment and testing.

2.2.5 Future Plans

Assuming positive developments with Japan are announced soon, we expect the financial support to improve. It should be noted that an important effect of the withdrawal of support is that most of the US collaborators have been forced to move to other work.

- EMCal Sensors: A second round of prototypes will be designed and ordered with rectangular layout; shielded traces, and Au pads.
- Tracker Sensors: The current prototypes will be evaluated, and if appropriate tested in a beam.
- KPiX: A new architecture with little (or no) deadtime will be evaluated. A decision will be made to develop this new architecture or incrementally.
- improve the existing design.
- The EMCal mechanical structure will be pushed towards a conceptual design.

2.2.6 Applications Outside of Linear Colliders

This work represents a significant step in the aggressive integration of silicon sensors with readout electronics, just short of integrating the electronics directly into the sensors. It has prompted consideration of this approach by CMS for calorimetry and by ATLAS for a muon system. It may have applications in sensors for light sources as well as other particle physics detectors.

2.3 Time Projection Chamber – Bonn

2.3.1 Collaborating Institutions

- CEA Saclay
- NIKHEF
- Fraunhofer Institut IZM, Berlin

2.3.2 Introduction

The University of Bonn is studying the pixelized readout of a TPC for the ILD detector. The readout is based on the Timepix ASIC with a triple GEM or Micromegas based gas amplification.

2.3.3 Recent Milestones

The first studies were based on the triple GEM setup with a single Timepix chip. This readout was mounted in a small test detector in the Bonn laboratory. Here, the working principle was tested with a long drift distance. It could be demonstrated that the transverse spatial resolution of the reconstructed primary electrons was close to the expected diffusion limit of single electrons. The results are summarized in the following publications: C. Brezina et al., Operation of a GEM-TPC with pixel readout, IEEE TNS, Vol. 59, No. 6, December 2012, pp. 3221-3228 J. Kaminski et al., Time projection chamber with triple GEM and pixel readout, NSS Conference Record, 2008, 2926-2929 C. Brezina et al., A Time Projection Chamber with triple GEM and pixel readout, 2009 JINST 4 P11015 J. Kaminski et al., Time projection chamber with triple GEM and highly granulated pixel readout, LP 2009, Conf. Proc. C0908171 (2009) 533-535 P. Schade et al., A large TPC prototype for a linear collider detector, NIMA 628 (2011) 128-132

The new focus are GridPix based detectors, where the gas amplification stage is a Micromegas produced in a postprocessing technique, which guarantees a high quality grid well aligned with the readout pixels. This approach was pioneered by NIKHEF and the University of Bonn has modified the production process together with the Fraunhofer Institut IZM so that a wafer-based production of GridPix detectors is standard by now. The new GridPixes were tested on small prototype detectors and also assembled in an 8 GridPix module for the Large Prototype detector at DESY. A successful test beam campaign was performed last year. M. Lupberger, The Pixel-TPC: first results from an 8-InGrid module, 2014 JINST 9 C01033 W. Koppert, GridPix detectors: Production and beam test results, NIMA 732 (2013) 245249 The current work is focused on a new LP module with about 100 GridPixes. This module is a demonstrator that larger areas (400 cm2) can be produced and operated. It shall be tested in the LP at the beginning of next year. For this a number of challenges have to be coped with. In particular commercial readout systems are not easily scalable. This is why Bonn has developed a cheap and easily

expandable system based on the Scalable Readout System (SRS) of the RD51 collaboration. In addition Bonn is developing the software for reconstructing and analyzing the test beam and simulation data. For this the LCTPC software framework of MarlinTPC is used. J. Abernathy et al., MarlinTPC: A Common Software Framework for TPC Development, NSS conference record, 2008, 1704-1708 Finally, Bonn also takes part in designing new pixel chips. To test the new digitization and readout techniques two test chips were designed in collaboration with N'IKHEF. Then Bonn also contributed to the design of the Timepix successor chip, Timepix3, which is being tested now: A. Kruth et al., GOSSIPO-3: measurements on the prototype of a read-out pixel chip for Micro- Pattern Gaseous Detectors, 2010 JINST 5 C12005 C. Brezina et al., GOSSIPO-4: Evaluation of a Novel PLL-Based TDC-Technique for the Readout of GridPix-Detectors, IEEE Trans. Nucl. Sci. Vol. PP Y. Fu et al., The charge pump PLL clock generator designed for the 1.56 ns bin size time-to-digital converter pixel array of the Timepix3 readout ASIC, 2014 JINST 9 C01052

2.3.4 Engineering Challenges

The production of a module with 100 GridPixes requires 4 main components: The production of a large number of GridPixes with sufficiently good quality. This has been addressed by the new production method and a large batch is being produced. The challenge of the readout is being addressed by the new readout system. Finally the distribution of the LV power to all ASICs and the cooling of the ASICs still are unclear, but since both challenges are similar for most readout electronics, standard solutions are expected to be adequate.

2.3.5 Future Plans

On a short term the production of the 100 ASIC module is the main goal at Bonn. If this module has been successfully operated, we are interested in replacing the Timepix ASIC by the Timepix3 ASIC and produce GridPix detectors with this improved chip. There are also some ideas of how to improve the grid structure and make it more reliable. Finally, the reconstruction and analysis software needs further improvement and has to be extended, so that simulated data for the final TPC (i.e. 10,000 hits per track) can be studied.

2.3.6 Applications Outside of Linear Colliders

A single InGrid detector will be installed this year in the CAST experiment for axion search. For a CLIC-TPC a highly granular (i.e. pixelized) readout structure is mandatory to lower the occupancy.

3 Electromagnetic Calorimeter R&D

3.1 Scintillator Strips

3.1.1 Collaborating Institutions

Nihon Dental University, Shinshu University, Tokyo University (ICEPP), Tsukuba University

3.1.2 Introduction

3.1.3 Recent Milestones

- introducing a new scintillation light readout scheme, with different scintillator strip shape by having better homogeneity
- photo-sensor of increased number of pixels in 1mmx1mm, this leads larger dynamic range for the calorimeter
- more experience on the FE read out board and ASICs

They are not published yet, instead some proceedings

3.1.4 Engineering Challenges

- wrapping the scintillator strip and align them on the FE read out layer automatically
- mass test facility for the read out layer

3.1.5 Future Plans

- optimizing scintillator layer: shape of scintillator strip, how to read out scintillation light, the location of photo-sensor, size and shape of photo-sensor and mass production scheme
- developing photo-sensor with Hamamatsu photonics company, to have lager dynamic range and mass test scheme
- establish a detector fabrication plan

3.1.6 Applications Outside of Linear Colliders

- photo-sensor named MPPC from Hamamatsu photonics INC is employed for the T2K experiment, CMS upgrade (HC-CAL), BELLII detector (endocarp muon)
- PET and SPECT development

3.2 Silicon Pads

3.2.1 Collaborating Institutions

If I put a cut on group with 1 FTE on It remains only LPNHE-Paris, LAL, Univ. of Tokyo and Kyushu University

3.2.2 Introduction

3.2.3 Recent Milestones

ELECTROMAGNETIC Calorimeter

- First development of PFA for dedicated detector (TESLA Report)
- First prototype of High granularity electromagnetic calorimeter (physics prototype, see publications in the CS report).
- First design of ECAL silicon tungsten for a full scale detector (From TESLA report to DBD 2013)
- R&D on scalable technology for all the involved large detector aspects (integration of embedded readoud chips, on thin supporting electronics boards, in self-supporting tungsten-Carbon mechanical elements ensuring the cooling and protection; all made of exchangeable elements with a quality control procedure; the associated DAQ).
- Realisation of a large self-supporting W-Carbon fiber structure with integrated stress monitoring (using Fiber Bragg Gratting)
- Recently: tests of 1st base sensor units of the technological prototype in beam

PFA:

- Development of Mokka an overlayer of the GEANT4 used for ILD, CLIC detectors, CALICE TB,
- Reconstruction tools adapted to the high granularity calorimeters (photon reconstruction [GARLIC], Advanced clustering [ARBOR], event displays [DRUID])

ILD integration & optimisation

- for the DBD: integration of all the ILD elements, placement of services, thorough estimation of total cost of the detector
- since DBD: re-optimisation of the ILD dimensionning, esp. for the Si-W ECAL using full PFA reconstruction.

3.2.4 Engineering Challenges

- Silicon wafer cost reduction when used for calorimetry; direct contact with producers established (Hamamatsu, On-Semi,).
- A chip with the good dynamic, noise, power dissipation (using power pulsing), etc;..
- Integration in a compact device, ensuring all the requests (precision: electronic and mechanic, heat production, reliability)
- Industrialisability of solutions; scalability of tests for a 100M channel detector.

3.2.5 Future Plans

Impossible. No way to see beyond next year (see IN2P3 recommendation) To recall, all the R&D will stop at the end of 2016, if there is no decision in Japan

3.2.6 Applications Outside of Linear Colliders

- CEPC, TLEP and directly today on CMS upgrade
- The compact Silicon-W design has been used in the PAMELA satellite (very similar to physics prototype)

4 Hadronic Calorimeter R&D

4.1 Scintillator Tiles

4.1.1 Collaborating Institutions

4.1.2 Introduction

4.1.3 Recent Milestones

4.1.4 Engineering Challenges

4.1.5 Future Plans

4.1.6 Applications Outside of Linear Colliders

4.2 Resistive Plate Chambers

4.2.1 Collaborating Institutions

4.2.2 Introduction

4.2.3 Recent Milestones

4.2.4 Engineering Challenges

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4.2.6 Applications Outside of Linear Colliders