PicoSecondLink

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Book of Abstracts

Contents

1

Electronics for Precision ToF Readout and other Aspects of Picosecond Timing

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I shall first describe the development and operation of the ToF readout electrons for the ATLAS Forward Protons (AFP) Detector that achieved a time resolution of 15ps per channel, independent of the ToF detector. The second aspect of the talk will detail our plans to develop radiation tolerant ToF electronics with picosecond timing based on the picoTDC chip. Finally, I will briefly touch on a possible new approach for radiation hard sub-picosecond timing.

2

Fast Advanced Scintillator Timing - COST Action TD1401

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Scintillator-based detectors have been very successful in high energy physics (HEP) calorimetry, medical imaging, and many other applications. In particular, the potential of such detectors to achieve precise timing information is of increasing importance for those applications. The demand to discriminate between closely spaced bunch trains in future highest luminosity accelerators and to deliver space points in addition to the traditional back-to-back line of response reconstruction algorithms of positron emission tomograph (PET), requires a further step in time resolution, i.e. below 100ps. The implications of such a radical improvement in time resolution come with dramatic benefits in many domains. HEP will profit from a significant increase in detection efficiency and the health sector from an unprecedented improvement in imaging quality and image reconstruction time. Such a 'paradigm'change, however, must go hand-in-hand with a similar break in the interdisciplinary domain of photon detection. Therefore, new expertise must be gained in the fields of scintillators, photodetectors, as well as electronics to develop ultrafast timing scintillator-based detectors.
The Trans Domain COST Action (FAST, Fast Advanced Scintillator Timing) aims to establish a multidisciplinary network that brings together European experts from academia and industry to ultimately achieve scintillator-based detectors with time precision better than 100ps and provides an excellent training opportunity for researchers interested in this domain. The FAST COST (Action TD1401) started on November 20 2014 and will end on November 19 2018. In this presentation we will present the FAST Action on its main achievements.

4

Timing amplifiers

Author: Eric Griesmayer[None]

I will give a presentation about the design rules for timing amplifiers with a practical example of our 2 GHz solution with 40 dB as used for pico-second measurements at CERN.

5

The ATLAS High-Granularity Timing Detector

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The large increase of pileup is one of the main experimental challenges for the HL-LHC physics program. A new powerful way to mitigate the effects of the pileup is to use high-precision timing information to distinguish between collisions occurring very close in space but well-separated in time.
In order to implement this feature to the ATLAS detector, the High-Granularity Timing Detector (HGTD) has been proposed for the Phase-II upgrade. The design of this new detector is based on low gain avalanche diodes (LGADs), and is set to achieve a 30 ps time resolution per minimum ionizing particle (MIP). This talk will focus on the requirements and developments necessary to meet this resolution in the HGTD. In particular, the design of the front-end electronics is an interesting challenge, as its contribution to the time resolution needs to be kept to a minimum in order match the excellent time resolution of the LGAD sensors.

6

Design and evaluation of a versatile sub-ns light pulser

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Many experimental setups for the calibration of photosensors require light sources with sub-nanosecond timing precision. Such sources are commercially available. However, their costs often prohibits applications with large numbers of sources. In contrast, simple circuits commonly used in the community, such as the Kapustinsky pulser, are limited to light pulses of few nanosecond duration. In this talk we present the design and performance evaluation of a sub-nanosecond light pulser based on an avalanche transistor circuit. The choice of LED or laser paired with variable biasing allows for a wide range of output intensities at nearly arbitrary wavelengths. Light curves down to 130ps std. are being achieved.

7

ASICs for picosecond timing and toward femtosecond timing

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Starting with a report on the performance of the recently installed Time Of Propagation detector for first Belle II collisions, a summary of lessons learned from next the advanced node PSEC4 ASIC is summarized. This leads logically to the AARDVARC ASIC, which will be summarized. Finally the presentation will conclude with presentation of important steps of the design of the RFpix ASIC, which is indeed for timing resolutions at the few hundred femtosecond level, and how this could enable a new generation of high timing and spatial resolution pixel detectors.

8

The need for UFSD for the EIC and Argonne's emerging R&D program

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We report on a detector concept, TOPSiDE, being developed for the EIC Electron-Ion Collider. TOPSiDE aims a the detection and identification of all particles created in electron-proton/ion collisions at the EIC while achieving the best possible momentum/energy resolution. The measurement of hadronic jets exploits the advantages offered by Particle Flow Algorithms (PFAs), which in turn require imaging calorimetry. Particle identification is achieved through time-of-flight measurements in the tracker and the electromagnetic calorimeter, necessitating the application of ultra-fast silicon sensors. Simulation studies showed that timing resolutions of 10 picoseconds are required to achieve pion-kaon separation up to 7 GeV/c.

9

Low-Gain Avalanche Diodes for Precision Timing in the CMS Endcap

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The Compact Muon Solenoid (CMS) detector at the CERN Large Hadron Collider (LHC) is undergoing an extensive Phase II upgrade program to prepare for the challenging conditions of the High-Luminosity LHC (HL-LHC). In particular, precision timing can offset the performance degradation due to event pileup at the HL-LHC, recovering the purity of vertices of current LHC conditions. As such, a new timing layer will be introduced to measure minimum ionizing particles (MIPs) with a time resolution of ˜ 30ps. The endcap region of this MIP Timing Detector (MTD) will be instrumented with a hermetic, single layer of silicon Low-Gain Avalanche Detectors (LGAD), covering the high radiation pseudo-rapidity region between $|\eta|$ = 1.6 to 3.0. Radiation tolerance studies of the LGAD indicate promising performances of 30 and 50 ps at fluences corresponding to $|\eta|$ = 2.5 and 3.0, respectively. In addition, the LGAD have intrinsic gain, which enhances the MIP signal and provides adequate signal-to-noise for good timing precision. We present the status of the R&D for the LGAD for the endcap region of the MTD and report on recent beam test results.

10

Last results from SAMPIC

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The SAMPIC chip is based on the concept of the Waveform Time to Digital converter introduced in 2013. It permits performing high precision timing measurements on detector signals computed from the waveform digitized at a several GSamples/s rate over a window defined by a trigger which can be defined internally or sent from outside. Since the first version of SAMPIC that proved the WTDC concept, new versions, each integrating 16 independent channels, have been developed.
1) to fix bugs,
2) to introduce new functionalities like complex triggers, ancillary measurements or interfacing with digital signals
3) and above all to make its integration easier in a low power compact system by reducing the number of required external components and minimizing the digital electronics required to drive it.
The talk will focus on the new possibilities offered by the latest chip version and will report its performance measured in lab and with detectors.

11

UFSD picosecond time resolution: present and future

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In this contribution, we will review the status of the UFSD project, that uses Low-Gain Avalanche Diodes optimized for high precision time and spatial measurements, giving emphasis to the time performances achieved by the current devices. We will present the roadmap to reach the challenging goal of a finely segmented device with a 10 ps time resolution.

12

Development of the Tachyon II, a Demonstration TOF-PET Camera with 127 ps Timing Resolution*

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We present the design studies and current status of the Tachyon II, a demonstration PET camera designed to optimize coincidence timing resolution. In addition to technology development, the purpose of camera is to measure the improvement in image quality afforded by time-of-flight.
The detector ring diameter is roughly 80 cm and is created using 0.6 cm cubes of FTRL scintillator (the trade name of an LSO analog manufactured by JT Technologies) that are individually coupled to 0.6 cm square SiPMs (J-Series manufactured by SensL). The camera consists of two crystals axially (thus 1.2 cm axial extent with two 0.6 cm rings) and two crystals radially (thus 1.2 cm thick, broken into two 0.6 cm depth of interaction bins).
The electronics does not utilize any custom ASICs but instead uses FPGAs to perform most of the processing. A timing edge is generated by a leading edge discriminator (i.e., a high speed comparator), and its arrival time is digitized using a novel TDC having 2.3 ps jitter that is implemented in the

FPGA. The integrated amplitude of the analog signal is digitized by a 1-bit sigma-delta ADC that is also implemented in the FPGA. A logarithmic time walk correction is performed to compensate for amplitude variations.
Components for the camera have been selected, purchased, and are currently being assembled. To date, ten modules have been assembled, each of which contains 24 scintillator crystals and 24 SiPMs. Measured against an identical single reference crystal / SiPM, the mean timing resolution for these 240 detector elements is 127 ps fwhm with a standard deviation of 3.7 ps.

* This work was supported in part by the Director, Office of Science, Office of Biological and Environmental Research, Biological Systems Science Division, U.S. Department of Energy under contract DE-AC02- 05CH11231, and in part by the National Institutes of Health, National Institute of Biomedical Imaging and Bioengineering, under Grants R01EB006085 and R21EB007081.

13

New developments in the detection of single soft photons

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In a single soft photon detector two essential processes occur: photoelectric absorption, converting the photon into a free photoelectron, and the multiplication of this electron, resulting in a detectable charge pulse. In the photomultiplier, amplification-by-multiplication occurs at a dynode, where a multiple of secondary electrons is reflected after the impact of an incoming energetic primary electron. We have developed the transmission dynode "tynode", in the form of a thin layer where secondary electrons are emitted at the bottom side after the impact of a primary electron at the top side. Using Atomic Layer Deposition (ALD) MgO at the emission side, a transmission secondary electron yield of 5.5 has been reached. A stack of 5 - 8 tynodes should produce a charge pulse sufficient to drive (digital) electronics after the impact of a single primary electron. Thanks to the short and identical straight line paths of the electrons crossing the gap between a tynode and the next one, the transient time is in the order of 50 ps, while all secondary electrons arrive within one ps on the readout anode below the tynode stack. By pixelising the anode in the form of a CMOS pixel chip, the required multiplication is minimised, and 2D spatial resolution is realised.
A stack of tynodes could be an alternative for Micro Channel Plates (MCPs), which have been improved significantly during the last decade. The time resolution of a tynode-based detector may potentially be better.
At present, photon detector development is focused on SiPMs because they are cheap, fast and efficient. Their dark noise, however, can't be suppressed. An MCP or a tynode stack is a noise-free amplifier, but these are always combined with a photocathode with a limited quantum efficiency (QE). The efficiency of a SiPM could be unity in theory, but the ultimate photon detector could be an assembly of a tynode stack or MCP (ultra fast, free of noise) and a high QE photocathode. With new MEMS technology, an active photocathode may be feasible with a QE much larger than the state-of-the-art value of 0.4.

14

Development of Crystal+SiPM Sensors for the Central CMS MIP Timing Detector

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The MIP Timing Detector (MTD) of the Compact Muon Solenoid (CMS) is designed to measure charged particles (MIPs) with a time resolution of 30ps with hermetic coverage up to a pseudo-rapidity of |η|=3. The central region consists of a cylindrical barrel based on LYSO:Ce crystals read out with SiPMs. The MTD reduces the pile-up effects expected under the High Luminosity LHC running conditions and brings new and unique capabilities to the CMS detector. The time information assigned to each track will enable the use of 4D reconstruction algorithms and will further discriminate in the time domain interaction vertices within the same bunch crossing to recover the track purity of vertices in current LHC conditions. We present test beam results obtained on crystal+SiPM sensors and the ongoing R&D targeting enhanced timing performance and radiation tolerance. Two strategies are being pursued to develop sensors with time resolution of 30 ps and uniform time response over the whole sensor surface: use of large area SiPMs with low density of cells and elongated crystal bars with double SiPM read-out.

15

Totem Timing detector: Sampic and UFSD at the LHC

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The new timing detector in the vertical Roman Pots of the Totem Experiment at LHC will be presented. Ultra Fast Silicon Detectors are read-out using the Sampic chip that sends data to CMS Data Acquisition system. Latest results and technical challenges will be discussed.

16

Characterization of Irradiated APDs and Broadband Amplifiers for Timing Applications

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In this talk, two topics are covered.
Avalanche Photo Diodes (APDs) produced by Radiation Monitoring Devices are examined as candidate timing detectors for HL-LHC applications. These APDs are operated at 1.8 kV, resulting in a gain of up to 500. The timing performance of the detectors is evaluated using a pulsed laser. The effects of radiation damage on current, signal amplitude, noise, and timing of the APDs are evaluated using detectors irradiated with neutrons up to $\Phi_{eq} = 10^{15}$ cm^{-2}.
Broadband amplifiers produced by CIVIDEC are characterized using a Low Gain Avalanche Detector and a pulsed laser. The performance of the amplifiers is evaluated in terms of signal amplitude, noise, signal to noise ratio and timing jitter.

17

ATLAS Forward Proton (AFP) time-of-flight (ToF) detector - construction & existing experiences

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In 2017 the ATLAS collaboration successfully completed the installation of the ATLAS Forward Proton (AFP) detector to measure diffractive protons leaving under very small angles (hundreds of micro radians) the ATLAS proton-proton interaction point. The AFP tags and measures forward protons scattered in single diffraction or hard central diffraction, where two protons are emitted and a central system is created. In addition, the AFP has a potential to measure two-photon exchange processes, and to be sensitive to eventual anomalous quartic couplings of Vector Bosons: γγW+W−, γγZZ, and γγγγ. Such measurements at high luminosities will be possible only due the combination of high resolution tracking (semi-edgeless 3D Silicon pixel) detectors and ultra-high precision ToF (Quartz-Cherenkov) detectors at both sides of the ATLAS detector. The ToF detector construction and experiences with its operation represent the subject of the talk.

18

PICOSEC: Charged particle timing to 24 picosecond precision with a Micromegas based detector

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The prospect of pile-up induced backgrounds at the High Luminosity LHC (HL-LHC)
has stimulated intense interest in developing technologies for charged particle detection with accurate timing at high rates.
The required accuracy follows directly from the nominal interaction distribution within a bunch crossing ($\sigma_z \sim 5$cm, $\sigma_t \sim 170$˜picoseconds˜(ps)).
A time resolution of the order of 20-30˜ps would lead to significant reduction of these backgrounds.
With this goal, we present a new detection concept called PICOSEC,
which is based on a two stage Micromegas detector coupled to a Cherenkov radiator and equipped with a photocathode.
First results obtained with this new detector yield a time resolution of 24˜ps for 150˜GeV muons, and 76˜ps for single photoelectrons.

19

SiPM readout circuitry for fast timing

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Review of SiPM model, front end circuits for SiPM readout, digitization techniques, system-On-chip solution and new trends. We will focus on fast timing applications.

20

Tests of an LGAD detetctor using a Linac for radiotherapy

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The talk will describe the timing detectors developed at the University of Kansas, optimized to work with LGAD sensors. In particular the presentation will present in detail the results obtained during the tests performed using an high rate gamma ray source designed for cancer treatments, at the St.Luke Hospital of Dublin.

21

Front-End electronics optimization for time tagging with Ultra-Fast Silicon Detectors

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The research of a few pico-seconds accuracy in timing measurements is currently a hot topic not only in the field of high energy physics but also in several applied physics branches. The Ultra Fast Silicon Detectors group of the Turin section of the Italian National Institute for Nuclear Physics (INFN) is involved in this challenge, developing extremely fast silicon sensors. This group spent the recent years simulating and designing Ultra-Fast Silicon Detectors (UFSDs), a particular type of Low Gain Avalanche Diodes (LGAD) optimized for timing application. These innovative devices for particle tracking are furthermore suitable for a very accurate time measure. The novelty improving the time tagging capability is enabled by the inclusion of a controlled low gain in the detector response, therefore increasing the detector output signal amplitude while keeping controlled the noise. A fast detecting system requires a high-performance front-end electronics to be coupled with the sensors. In cutting-edge experiments like the High-Luminosity LHC, both high spatial and time resolutions are strict constraints. Therefore, highly segmented sensors are employed, implying high density of channels and integrated VLSI electronics. Thanks to the experience gained with the development and the characterization of a first Application Specific Integrated Circuit (ASIC) prototypes, named TOFFEE, the UFSD group is currently exploring various design possibilities for front-end electronics to be coupled with UFSDs. The group design approach is based on the study of different transimpedance amplifier architectures, with a dedicated study of the parasitic components associated to the layout structures. Moreover, taking advantage of different scaled and ultra-scaled CMOS technology nodes, it will be possible to compare among various technology features changing with the technology scaling (e.g. the transistor transcoductance).
After an extensive phase of study and design simulation, our group is planning to develop a low-power, multi-channel front-end ASIC for time tagging with UFSD.

22

Status of the research in the TOFFEE ASIC

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The upgrade of the High Energy Physics experiments worldwide lead to very strict requirements in terms of timing capabilities of silicon sensors and front-end electronics.
In the case of the high luminosity LHC ˜150-200 events per bunch crossing are expected which introduce hundreds of overlapping events (pile-up) making really tricky to take and analyse data.
In this context time tagging is becoming a very important tool for pile-up mitigation allowing to distinguish events overlapping in space but separated in time by few tens of picoseconds.
For this reason, the so-called Ultra Fast Silicon Detectors (UFSD) and TOFFEE, a fully custom readout ASIC, have been developed.
The TOFFEE chip has been designed in a standard 0.11 μm CMOS technology for the readout of signals produced by 50 μm thick UFSD sensors to cope with the CMS-TOTEM Precision Proton Spectrometer (CT-PPS) time resolution requirement of 30 ps per detector plane. The ASIC contains 8 channels each composed by a charge sensitive amplifier, a single threshold discriminator, a stretcher and LVDS driver. The full chain is optimized for capacitances of 3-10 pF and to manage input charges from 3 fC up to 8 fC. The ASIC has been received from foundry in September 2016 and has been extensively tested obtaining a time resolution of 50 ps with a power consumption of 14.4 mW/ch. This talk reports on the status of the research in the TOFFEE ASIC.