

The 27th International Workshop on Vertex Detectors

Sunday 21 October 2018 - Friday 26 October 2018

_s40s.png _s40s.bb _s40s.png”

Book of Abstracts

Contents

3D integration and silicon pixel detectors 113	1
3D integration and silicon pixel detectors 51	1
3D integration and silicon pixel detectors 11	1
ATLAS ITk Strip Detector for High-Luminosity LHC 78	1
ATLAS ITk Strip Detector for High-Luminosity LHC 34	1
Advanced Cooling overview 114	2
Advanced mechanics for silicon tracker 115	2
Advanced mechanics for silicon tracker 50	2
Advanced mechanics for silicon tracker 44	2
BELLE II inner pixel detector upgrade 76	3
BELLE II inner pixel detector upgrade 2	3
Belle II Silicon Strip Detector Upgrade 77	3
Belle II Silicon Strip Detector Upgrade 26	3
Construction and Quality Assurance of the Belle II Silicon Vertex Detector 31	4
Cooling the CMS Phase II Inner Tracker, Challenges and Solutions 25	4
Depleted CMOS for H-LHC 109	5
Depleted CMOS for H-LHC 94	5
Development of SOI Monolithic Pixel Detector for Fine Measure- ment of Space and Time 97	5
Development of SOI Monolithic Pixel Detector for Fine Measurement of Space and Time 32	5
Diamond Detector Development and Plans - The Status of the RD42 Collaboration 100 . .	6
Establishment of characterization system for testing multi silicon micro-strip sensors at the University of Delhi 29	6
Extremely radiation-hard technologies: 3D Sensors 68	7

Extremely radiation-hard technologies: 3D sensors 30	7
Fast timing and 4D tracking with UFSD detectors 85	8
Fast timing and 4D tracking with UFSD detectors 7	8
Hybridization techniques 116	8
ITk Strip Module Design and Performance 12	8
Interconnects and Assembly Technologies for Hybrid Pixel De- tectors 98	9
Interconnects and Assembly Technologies for Hybrid Pixel Detectors 10	9
LHCb tracker upgrade 81	10
LHCb vertex locator upgrade 75	10
Operational Experience and commissioning of the Belle II tracker 43	10
Operational Experience on Current detectors at LHCb experiment 57	10
Operational Experience on Current silicon strip detector in CMS Experiment 19	10
Operational Experience on Current tracker at ATLAS experiment 54	11
Operational Experience on Current tracker at ATLAS experiment 41	11
Operational Experience on Pixel tracker at CMS experiment 55	11
Operational Experience on silicon tracter detector in BELLEII experiment 59	11
Operational Experience on strip tracker at CMS experiment 56	12
Operational Experience on tracker detectors in ALICE experiment 58	12
Operational experience with the current tracker in ALICE 33	12
Particles tracking at fluences above 1E16 n/cm2 82	12
Particles tracking at fluences above 1E16 n/cm2 5	13
Performance Studies of the Belle II Silicon Vertex Detector 22	13
Performance of prototype modules of CMS outer tracker for HL-LHC in test beams 15 . .	13
Pixel detector for ATLAS upgrade 73	14
Pixel detector for ATLAS upgrade 24	14
Pixel detector for CMS upgrade 74	14
Pixel detector for CMS upgrade 40	14
Poster Summary 52	15
Quality control for ATLAS ITk strip sensor production 35	15
RD42 Status report 64	15

RD50 Status report 65	16
RD50 activities on radiation tolerant silicon detectors 8	16
RD53-A and RD53-B plan and status 112	16
Radiation damage modeling: TCAD simulation 23	16
Radiation damage modeling:TCAD simulation 70	17
Radiation hardness for RD53 66	17
Radiation hardness studies and irradiation test results of RD53A chip, a large scale chip demonstrator for pixel readout at the HL-LHC 101	17
Radiation tolerance and time resolution of depleted CMOS sensors 84	18
Radiation tolerance and time resolution of depleted CMOS sensors 28	18
Results and perspectives from RD53 on the Next Generation Readout Chips for HL-LHC silicon pixel detector phase 2 upgrades 42	19
ResultsandperspectivesfromRD53ontheNextGenerationRead- out Chips for HL-LHC silicon pixel detector phase 2 upgrades 95	19
Review on depleted CMOS 110	19
Review on depleted CMOS 96	20
Review on depleted CMOS 104	20
SiPM for timing 83	20
Silicon tracker detector for the ALICE upgrade 79	20
Silicon tracker detector for the ALICE upgrade 37	20
Spatial Resolution of the Belle II Silicon Vertex Detector 20	21
Status of AFP 60	21
Status of AFP 13	21
Status of CT-PPS 61	22
Status of CT-PPS 6	22
Status of HgCAL in CMS upgrade 72	22
Status of SoI Sensors 111	23
Status of pnCCDs 71	23
Status of pnCCDs 45	23
Status of silicon detector R&D at CLIC 106	23
Status of silicon detector R&D at CLIC 86	23

Status of silicon detector R&D at CLIC 3	24
Status of silicon tracker in NA62 63	24
Status of silicon tracker in NA62 48	24
Status of the Tracker Design for FCChh 107	24
Status of the Tracker Design for FCChh 87	25
Status of the Tracker Design for FCChh 14	25
Status of tracking detectors at ILC 108	25
Status of tracking detectors at ILC 88	25
Status of tracking detectors at ILC 47	25
Study of damages induced on ATLAS silicon by fast extracted and intense proton beam irradiation 69	26
Study of damages induced on ATLAS silicon by fast extracted and intense proton beam irradiation 16	26
System design challenges for CO2 evaporative cooling in tracking detectors 18	27
SystemdesignchallengesforCO2evaporativecoolingintracking detectors 49	27
The Belle II PXD 17	27
The CMS Outer Tracker Upgrade for the High Luminosity LHC 80	28
The CMS Outer Tracker Upgrade for the High Luminosity LHC 9	28
The LHCb VELO Upgrade 105	28
The Malta CMOS pixel detector prototype for the ATLAS Pixel ITK 67	29
The Malta CMOS pixel detector prototype for the ATLAS Pixel ITK 1	29
The STAR Heavy Flavor Tracker: Embedding Simulations into a High Multiplicity Environment 62	29
The STAR Heavy Flavor Tracker: Embedding Simulations into a High Multiplicity Environment 39	30
Timepix3 performance in pulsed power operation 21	30
Tracking and vertexing in ATLAS experiment 90	30
Tracking and vertexing in BELLE II 93	31
Tracking and vertexing in BELLE II 38	31
Tracking and vertexing in CMS experiment 102	31
Tracking and vertexing in CMS experiment 89	31

Tracking and vertexing in LHCb 92 32

Tracking and vertexing in LHCb 27 32

Tracking and vertexing in the ALICE experiment at the LHC 36 32

Tracking and vertexing using the ATLAS detector 103 33

Tracking and vertexing in the ALICE experiment at the LHC 91 33

Wireless data transmission 99 33

Workshop Summary 53 33

experience in operating the silicon detectors 46 34

Electronics and System Integration: / 113**3D integration and silicon pixel detectors****Corresponding Author:** valerio.re@unibg.it**Future Collider Experiments / 51****3D integration and silicon pixel detectors****Corresponding Authors:** valerio.re@unibg.it, valerio.dao@cern.ch

11

3D integration and silicon pixel detectors**Author:** Valerio Re¹¹ INFN**Corresponding Author:** valerio.re@unibg.it

3D integration technologies have generated a wide interest in the silicon pixel sensors and front-end electronics communities. They have the potential to lead to the fabrication of multilayer high performance devices with no dead area, where each layer is optimized for its function (particle sensing, analog signal amplification and filtering, digital memory and readout,...). Recent developments associated with industrial and scientific applications of CMOS image sensors have reinvigorated the interest of the community, showing the potential of advanced interconnection technologies in the design of high performance detectors. This paper will review the results that the community got so far, and assess the current status of R&D work on 3D integration applied to particle detection systems. Finally, the prospects of 3D integration for the future generation of pixel detectors (either hybrid or monolithic) will be discussed.

Detectors in design and construction / 78**ATLAS ITk Strip Detector for High-Luminosity LHC****Corresponding Author:** andrew.blue@cern.ch

34

ATLAS ITk Strip Detector for High-Luminosity LHC**Author:** Andrew Blue¹¹ University of Glasgow (GB)**Corresponding Author:** andrew.blue@cern.ch

The High Luminosity Large Hadron Collider (HL-LHC) will operate at an ultimate peak instantaneous luminosity of $7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ which corresponds to approximately 200 inelastic proton-proton collisions per beam crossing (pile-up). It will be operational for more than 10 years and in that time ATLAS aims for a total data set of 4000 fb^{-1} . To operate at the higher data rates, withstand the radiation levels, and maintain low occupancy in the high pile-up environment, the current ATLAS Inner Detector (ID) will be replaced by a new Inner Tracker (ITk). The ITk will be an all-silicon tracking system that consists of a pixel detector at small radius close to the beam line and a large area strip tracker surrounding it.

This contribution focuses on the strip region of the ITk. The central part of the strips tracker will be composed of rectangular “short” ($\sim 2.5 \text{ cm}$) and “long” ($\sim 5 \text{ cm}$) strip sensors. The forward regions of the strips tracker consist of 6 disks per side, with trapezoidal shaped microstrip sensors of various lengths and strip pitches. In response to the needs of the strip region for the ITk, highly modular structures are being studied and developed, called staves for the central region and petals for the forward regions (end-caps). These structures integrate large numbers of sensors and readout electronics, with precision light weight mechanical elements and cooling structures.

A strong prototyping effort has been put in place over the course of the last years in order to optimize the ITk strips system. This contribution summarizes the R&D activities performed by the numerous institutes within the Strips ITk collaboration showing the transition from R&D to final production.

Electronics and System Integration: / 114

Advanced Cooling overview

Corresponding Author: paola.tropea@cern.ch

Electronics and System Integration: / 115

Advanced mechanics for silicon tracker

Corresponding Author: georg.viehhauser@physics.ox.ac.uk

Future Collider Experiments / 50

Advanced mechanics for silicon tracker

44

Advanced mechanics for silicon tracker

Author: Georg Viehhauser¹

¹ *University of Oxford (GB)*

Corresponding Author: georg.viehhauser@physics.ox.ac.uk

In this presentation first the complex demands on the mechanics of silicon tracking and vertexing systems in terms of stability and thermal performance will be discussed. I will then discuss examples of how these issues have been addressed in current detector systems and discuss some ideas for the mechanics of future trackers.

Detectors in design and construction / 76

BELLE II inner pixel detector upgrade

Corresponding Author: chk@hll.mpg.de

2

BELLE II inner pixel detector upgrade

Author: Christian Koffmane¹

¹ *Halbleiterlabor der Max-Planck-Gesellschaft*

Corresponding Author: chk@hll.mpg.de

The Belle II experiment is a substantial upgrade of the Belle detector and will operate at the SuperKEKB energy-asymmetric e^+/e^- collider. The accelerator has already successfully completed the first phase of commissioning in 2016 and the first electron-positron collisions in Belle II were recorded in April 2018. Belle II features a newly designed silicon vertex detector based on double-sided strip and DEPFET pixel detectors. Currently, a subset of the detector is installed (Phase 2 of the experiment) while background conditions are being determined; installation of the full detector (Phase 3) will be completed by the end of 2018.

The paper will discuss the lessons learned during module and ladder production and show results from the sector of PXD operated during SuperKEKB phase2.

Detectors in design and construction / 77

Belle II Silicon Strip Detector Upgrade

Corresponding Author: takeo.higuchi@ipmu.jp

26

Belle II Silicon Strip Detector Upgrade

Author: Takeo Higuchi¹

¹ *Kavli IPMU*

Corresponding Author: takeo.higuchi@ipmu.jp

The Belle II experiment at the SuperKEKB accelerator in KEK, Japan is the next-generation luminosity frontier experiment, which will operate at an unprecedented instantaneous luminosity of $81035 \text{ cm}^{-2}\text{s}^{-1}$, about 40 times larger than its predecessor Belle experiment. The Belle II vertex detector

consists of a two-layer DEPFET based pixel detector (PXD) and four-layer silicon vertex detector (SVD). Each SVD layer is formed by cylindrically arranged ladders around the beam pipe, and each ladder is composed of an array of double-sided silicon strip sensors. The innermost, second, third, and outermost SVD layers are composed of seven, ten, twelve, and sixteen ladders, respectively. The SVD has a characteristic lantern structure in order to increase the detector acceptance on the forward side while reducing the total number of sensors required. Most of the ladders have a kinked shape to account for the lantern structure.

We had developed the ladder assembly procedure after an intensive R&D program because of the very complicated structure of the ladders. All the ladders needed for the Belle II operation had been assembled and qualified at the SVD institutes, and then, they were transported to KEK. These ladders for the operation had been successfully mounted to the SVD structure, which is composed of two lengthwise half cylinders called half shells. Cooling pipes to chill the readout ASICs on the ladders by dual-phase CO₂ were also mounted on the half shells. The fully fabricated first half-shell is under an integrated commissioning test using cosmic ray muons. Several tracks of the cosmic ray muons are already clearly observed by the first half-shell ladders. The commissioning test for the second half-shell is foreseen very soon.

Besides the commissioning test of the half shells, two PXD and four SVD ladders are installed on the SuperKEKB beam line to test the performance of the ladders especially in terms of the position resolution of cosmic ray muons and the particles from the e⁺e⁻ collisions.

In this talk, we present the latest commissioning test results of the Belle II SVD and the results of the early performance test of the partial SVD installed on the SuperKEKB accelerator.

31

Construction and Quality Assurance of the Belle II Silicon Vertex Detector

Author: Resmi P K¹

¹ *IIT Madras*

Corresponding Author: resmipk@physics.iitm.ac.in

The Belle II experiment at the interaction point of the SuperKEKB e⁺e⁻ collider at KEK, Tsukuba, Japan is expected to collect data corresponding to an integrated luminosity of 50 ab⁻¹ that will allow to search for signals of beyond-the-standard-model physics via precision measurements and searches for very rare decays. At its heart lies a six-layer vertex detector consisting of two layers of pixel detectors (PXD) and four layers of double-sided silicon microstrip detectors (SVD). Precise vertexing as provided by this device is essential for measurements of time-dependent CP violation. Crucial aspects of the SVD assembly are precise alignment, as well as rigorous electrical and geometrical quality assurance. We present an overview of the construction of SVD, including the precision gluing of SVD component modules and the wire-bonding of various electrical components. We also discuss the electrical and geometrical quality assurance tests.

25

Cooling the CMS Phase II Inner Tracker, Challenges and Solutions

Author: Souvik Das¹

¹ *Purdue University (US)*

Corresponding Author: souvik.das@cern.ch

The High Luminosity LHC will reach an instantaneous luminosity of $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ with 140 to 200 pp collisions per bunch crossing and collect a total of 3 ab^{-1} of 14 TeV data. To cope with these challenging data taking conditions, the CMS Inner Tracker will be rebuilt for Phase II Upgrades. To limit particle occupancy to the per mille level, and improve tracking and vertexing performance, we will increase the granularity of the sensors. This will result in power dissipation of approximately 50 kW. For sensors to survive the radiation close to the beam pipe, we will need to maintain them around -20 C. Thus, cooling the detector will be of paramount importance. We present a scheme for cooling built into the structural support of the Pixel Detector. The cooling system is studied and optimized through finite element analysis simulations. The simulations are informed by experimental measurements of the thermal transport properties of bulk and interface materials performed in novel, custom-made apparatuses.

Electronics and System Integration: / 109

Depleted CMOS for H-LHC

Corresponding Author: heinz.pernegger@cern.ch

Fast timing technologies / 94

Depleted CMOS for H-LHC

Corresponding Author: heinz.pernegger@cern.ch

Fast timing technologies / 97

Development of SOI Monolithic Pixel Detector for Fine Measurement of Space and Time

Corresponding Author: hara@hep.px.tsukuba.ac.jp

32

Development of SOI Monolithic Pixel Detector for Fine Measurement of Space and Time

Authors: Kazuhiko Hara¹ ; Shun Ono² ; Toru Tsuboyama³ ; Miho Yamada⁴ ; Yasuo Arai⁴ ; Junji Haba² ; Yoichi Ikegami⁴ ; Manabu Togawa⁴ ; Hiroki Yamauchi⁵ ; Ryuhei Abe⁵ ; Shikie Iwanami⁵ ; Hitoshi Murakami⁵ ; Kevin Watanabe⁵

¹ *University of Tsukuba (JP)*

² *KEK*

³ *KEK, High Energy Accelerator Research Organization*

⁴ *High Energy Accelerator Research Organization (JP)*

⁵ *University of Tsukuba*

Corresponding Authors: ikegami@post.kek.jp, yasuo.arai@kek.jp, manabu.togawa@cern.ch, toru.tsuboyama@kek.jp, miho.yamada@cern.ch, hara@hep.px.tsukuba.ac.jp, junji.haba@kek.jp, onos@post.kek.jp

SOFIST is an SOI pixel sensor in development to achieve fine measurement of both space and time, adopting the performance specifications of the International Linear Collider (ILC) vertex detector for the sensor design. The SOFIST is to consist of multiple-stage hit-charge and hit-time memories in each of $20\ \mu\text{m} \times 20\ \mu\text{m}$ pixels with 3D integration technology. The SOFIST1 and SOFIST2 chips have been beam-tested to verify the space and time measurement performance, respectively. Spatial resolution of 1.3 to $1.4\ \mu\text{m}$ was obtained for 200-500 μm depletion thicknesses by means of a simple charge-weighting method and $2.0\ \mu\text{s}$ by measuring the ramp voltage height. Status of SOFIST3 (both functions integrated in $30\ \mu\text{m} \times 30\ \mu\text{m}$ pixels) and SOFIST4 (3D integrated in $20\ \mu\text{m} \times 20\ \mu\text{m}$ pixels) development is reported.

100

Diamond Detector Development and Plans - The Status of the RD42 Collaboration

Author: Harris Kagan¹

¹ *Ohio State University (US)*

Corresponding Author: harris.kagan@cern.ch

At present most experiments at the CERN Large Hadron Collider (LHC) are planning upgrades in the next 5-10 years for their innermost tracking layers as well as luminosity monitors to be able to take data as the luminosity increases and CERN moves toward the High Luminosity-LHC (HL-LHC). These upgrades will most likely require more radiation tolerant technologies than exist today. As a result this is one area of intense research. Chemical Vapor Deposition (CVD) diamond has been used extensively and successfully in beam conditions/beam loss monitors as the innermost detectors in the highest radiation areas of essentially all LHC experiments. The startup of the LHC in 2015 brought a new milestone where the first diamond pixel modules were installed in an LHC experiment (ATLAS) and successfully began taking data. As a result, this material is now being discussed as a possible sensor material for tracking very close to the interaction region and for pixelated beam conditions/beam loss monitors of the LHC/HL-LHC upgrades where the most extreme radiation conditions will exist.

The RD42 collaboration at CERN is leading the effort to use CVD diamond as a material for tracking detectors operating in extreme radiation environments. During the last three years the RD42 group has succeeded in producing and measuring a number of devices to address specific issues related to use at the HL-LHC. We will present status of the RD42 project with emphasis on recent beam test results. In particular we present the latest results on material development, the most recent results on radiation tolerance and the independence of signal size on incident particle rate in poly-crystalline CVD diamond pad and pixel detectors over a range of particle fluxes up to $20\ \text{MHz}/\text{cm}^2$, measurements of charge collection in 3D diamond devices and the most recent beam test results from small cell 3D diamond pixel detectors. In addition we will present the plans for future use of the most recent devices.

29

Establishment of characterization system for testing multi silicon micro-strip sensors at the University of Delhi

Author: Chakresh Jain¹

Co-authors: Geetika Jain¹ ; Abhijeet¹ ; Ajay Kumar¹ ; Ashutosh Bhardwaj¹ ; Kirti Ranjan¹

¹ *Centre for Detector and Related Software Technology, Department of Physics and Astrophysics, University of Delhi, Delhi-110007*

Corresponding Authors: kirtiranjan@gmail.com, go2ashu@gmail.com, ajkumar85@gmail.com, abhijeetsisodia89@gmail.com, interuniversechakresh15@gmail.com, geetika.jain@cern.ch

A major concern with the use of silicon sensor in nuclear and particle physics experiments is its survival in the intense radiation environment. The unprecedented increase in fluence in these experiments affects its long-term sustainability due to both bulk and surface damage, resulting in the deterioration of its static and dynamic properties. Hence, stringent tolerance criteria are imposed on these sensors to maintain the physics performance of an experiment. This necessitates the testing of the silicon sensors' performance under temperature and humidity controlled, dark and dust free, environment.

Our Group at the University of Delhi is in the process of establishing such a characterization system, for the first time in India, for testing a large array of silicon micro-strip sensors. A set of electrical characterization units, capable of providing 3000 V and measuring pico-Ampere currents and pico-Farad capacitances, are installed in the facility. Among other features, the probe station has a capability to translate in three directions, with a step size of 2 micro-meter over the range of 20 cm in XY directions. The entire system is interfaced through the Automated Characterization Suite (ACS) software and can be programmed in a such a way that one does not need to intervene manually as it switches from one silicon strip to another. Several measurements involving currents, capacitances and resistances can be performed for the total, strip and inter-strip parameters. It is primarily envisioned to utilize the setup for the qualification of micro-strip silicon sensors for the CMS outer tracker in the high-luminosity LHC upgrade. In this work, we present the details of this state-of-the-art characterization system and measurements performed on silicon strip sensors.

Radiation Hardness / 68

Extremely radiation-hard technologies: 3D Sensors

Corresponding Author: giulio.tiziano.forcolin@cern.ch

30

Extremely radiation-hard technologies: 3D sensors

Authors: Giulio Tiziano Forcolin¹ ; Roberto Mendicino² ; Gian Franco Dalla Betta¹

¹ *Universita degli Studi di Trento è INFN (IT)*

² *UNITN*

Corresponding Authors: gian.franco.dalla.betta@cern.ch, roberto.mendicino@unitn.it, giulio.tiziano.forcolin@cern.ch

3D sensors have emerged as the most radiation-hard silicon-based technology for vertex detectors. Their radiation tolerance is due to their structure, where vertical electrodes penetrate the substrate for most or all of its thickness. The inter-electrode separation is therefore determined by the layout and can be made much smaller than the substrate thickness. As a result, sensors can be operated at relatively low bias voltages even after large radiation fluences (~200 V at most), leading to significant savings in terms of power dissipation and strongly mitigating charge trapping effects. Remarkably good results have so far been reported for 3D sensors fabricated at different processing facilities, achieving a comparable performance level, evidence of the intrinsically geometrical nature of the radiation hardness properties.

As the technology has progressed through the years, it has been possible to steadily improve the device characteristics by downscaling the electrode geometries. As an example, the 3D pixels installed in the ATLAS Insertable B-Layer have an inter-electrode separation of $\sim 67 \mu\text{m}$: they were qualified for the benchmark fluence of $5 \times 10^{15} \text{ n}_{eq} \text{ cm}^{-2}$, but were also proved to be fully efficient up to $\sim 1 \times 10^{16} \text{ n}_{eq} \text{ cm}^{-2}$. Conversely, the 3D pixels designed for the innermost tracking layers at the High Luminosity LHC (HL-LHC) have high granularity (e.g. $50 \times 50 \mu\text{m}^2$ pixel size) and an inter-electrode separation as small as $\sim 35 \mu\text{m}$. In a beam test, after irradiation at the extreme fluence of $3 \times 10^{16} \text{ n}_{eq} \text{ cm}^{-2}$, they exhibit an efficiency greater than 97% at just 150 V.

This talk will provide a comprehensive and up-to-date overview of 3D sensor performance in terms of radiation hardness. Selected results from the electrical and functional characterization of sensors from different manufacturers will be discussed, as well as the main design and technological issues relevant to the new generation of small pitch 3D sensors for the HL-LHC. The potential advantages in terms of radiation hardness and timing performance attainable by implementing trenches rather than cylindrical electrodes will also be addressed.

Fast timing technologies / 85

Fast timing and 4D tracking with UFSD detectors

Corresponding Author: amedeo.staiano@to.infn.it

7

Fast timing and 4D tracking with UFSD detectors

Author: Roberta Arcidiacono¹

¹ *Universita e INFN Torino (IT)*

Corresponding Author: roberta.arcidiacono@cern.ch

In this contribution, I will review the growing interest in implementing large area fast timing detectors with a time resolution of 30-50 ps based on low gain avalanche detectors. This interest is spurred as timing information is a very effective tool in pile-up rejection. Large scale high-precision timing detectors face formidable challenges in almost every aspect: sensors performance, their segmentation and radiation resistance, very low power and low noise electronics, cooling, low material budget and large data volume. In my talk I will also present the progress towards the realization of 4D-tracking detectors, which combine the excellent spatial resolution of silicon trackers to fast timing measurement. The current status of these developments in detectors for high-energy physics, and its possible use at HL-LHC, will be reported.

Electronics and System Integration: / 116

Hybridization techniques

Corresponding Author: thomas.fritzsch@izm.fraunhofer.de

12

ITk Strip Module Design and Performance

Author: Martin Sykora¹

¹ Charles University (CZ)

Corresponding Author: martin.sykora@cern.ch

The all-silicon ATLAS Inner Tracker (ITk), vertexing and tracking device for the High-Luminosity LHC project, should operate at an ultimate peak instantaneous luminosity up to $7.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ corresponding to approximately 200 inelastic proton-proton interactions per beam crossing. The ITk Strip Detector will consist of a four-layer barrel and a forward region composed of six disks on each side of the barrel. They will be composed of individual structures called staves and petals, whose production will require almost 18,000 single-sided strip modules of 8 different designs with the hybrid circuits carrying the front-end microelectronics ASICs glued to the sensor surface. The sensing elements are high resistivity n-in-p silicon strips capable of withstanding fluences up to $1.2 \times 10^{15} \text{neq/cm}^2$. Both irradiated and non-irradiated samples of strip modules undergo testing procedures including test beam campaigns supplemented by laser and beta source tests to check that they meet the design requirements of the detector. Detail description of the strip module design will be presented as well as performance characteristics from the prototype tests.

Fast timing technologies / 98

Interconnects and Assembly Technologies for Hybrid Pixel Detectors

Corresponding Author: thomas.fritzsich@izm.fraunhofer.de

10

Interconnects and Assembly Technologies for Hybrid Pixel Detectors

Authors: Thomas Fritzsich¹ ; Hermann Oppermann¹ ; Mario Rothermund¹

¹ Fraunhofer IZM

Corresponding Authors: mario.rothermund@izm.fraunhofer.de, thomas.fritzsich@izm.fraunhofer.de, hermann.oppermann@izm.fraunhofer.de

Hybrid pixel detector modules are state of the art in vertex detectors of the high-energy physics as well as the x-ray cameras in synchrotron radiation experiments. Each module of such a detector consists of a sensor chip and one or more electronic readout chips. In order to connect every pixel on the sensor with an electronic readout cell both parts are bump bonded together.

Solder bump bonding is one of the standard technologies for bonding of hybrid pixel detector modules. Using this technology readout chips with Indium, tin-silver or lead-tin solder bumps are connected to the under bump metallization on sensor pixel pad side. In addition to the well-known solder bump bonding technology the presentation will give an overview of alternative bonding technologies like transient liquid phase bonding (TLPB), thermo-compression bonding or metal-oxide-hybrid bonding. But these technologies require alternative interconnect structures and bonding process parameters. On the other hand these bonding technologies will show advantages either in terms of operating conditions of the hybrid modules or can be used for instance for the bonding of very thin chips.

Based on the description of the alternative bonding technologies examples of use will be given in this presentation. The use cases will describe hybrid module bonding for pixel detector applications as well as other applications like silicon interposers or 3D electronic packages with through silicon via (TSV).

Detectors in design and construction / 81

LHCb tracker upgrade

Corresponding Author: mauro.citterio@mi.infn.it

Detectors in design and construction / 75

LHCb vertex locator upgrade

Corresponding Author: deepanwita.dutta@cern.ch

43

Operational Experience and commissioning of the Belle II tracker

Author: Benjamin Schwenker¹

¹ *Göttingen University*

Corresponding Author: benjamin.schwenker@phys.uni-goettingen.de

The construction of the new accelerator at the Super Flavor Factory in Tsukuba, Japan, has been finalized and the commissioning of its detector (Belle II) has started. This new e+e- machine (SuperKEKB) will deliver an instantaneous luminosity of $8 \cdot 10^{35} \text{ cm}^{-2}\text{s}^{-1}$, which is 40 times higher than the world record set by KEKB. In order to be able to fully exploit the increased number of events and provide high precision measurements of the decay vertex of the B meson systems in such a harsh environment, the Belle II detector will include a new 6 layer silicon vertex detector. Close to the beam pipe, 2 pixel and 4 double-sided strip detector layers will be installed. During its first data taking period in 2018, the inner volume of the Belle II detector was only partially equipped with the final vertex detector technologies. The remaining volume was covered with dedicated radiation monitors, collectively called BEAST II, in order to investigate the particle and synchrotron radiation backgrounds near the interaction point. In this talk, the milestones of the commissioning of the Belle II tracker and BEAST II are reviewed and the detector performance and selected background measurements will be presented.

Operational Experience on Current detectors / 57

Operational Experience on Current detectors at LHCb experiment

Corresponding Author: david.hutchcroft@cern.ch

19

Operational Experience on Current silicon strip detector in CMS Experiment

Author: Ivan Shvetsov¹

¹ *KIT - Karlsruhe Institute of Technology (DE)*

Corresponding Author: ivan.shvetsov@cern.ch

The CMS outer silicon strip tracker with its more than 15000 silicon modules and 200m² of active silicon area is in its tenth year of operation at the LHC. We present the performance of the detector in the LHC Run 2 data taking. Results for signal-to-noise, hit efficiency and single hit resolution will be presented. We review the behavior of the system when running at beyond-design instantaneous luminosity and describe challenges observed under these conditions. The evolution of detector parameters under the influence of radiation damage will be presented and compared to simulations.

Operational Experience on Current detectors / 54

Operational Experience on Current tracker at ATLAS experiment

Corresponding Author: kathrin.becker@cern.ch

41

Operational Experience on Current tracker at ATLAS experiment

Author: Kathrin Becker¹

¹ *Albert Ludwigs Universitaet Freiburg (DE)*

Corresponding Author: kathrin.becker@cern.ch

The tracking and vertexing performance of the ATLAS detector relies critically on the silicon detector consisting of a strip detector (SCT) and a pixel detector. With the excellent performance of the LHC in Run 2, the silicon tracking detectors have been operated well beyond the original design specifications. The status and limitations of the detectors with respect to band width, radiation damage to the sensors, and the impact of SEUs on readout, are presented. Also the approaches in hardware, software, and calibration to maintain excellent performance during permanent high luminosity operation are discussed. Apart from reflecting on Run 2, an outlook is given to the activities in the upcoming long shut-down and the operational challenges of LHC Run 3.

Operational Experience on Current detectors / 55

Operational Experience on Pixel tracker at CMS experiment

Corresponding Author: satoshi.hasegawa@cern.ch

Operational Experience on Current detectors / 59

Operational Experience on silicon tracker detector in BELLEII experiment

Corresponding Author: benjamin.schwenker@phys.uni-goettingen.de

Operational Experience on Current detectors / 56

Operational Experience on strip tracker at CMS experiment

Corresponding Author: ivan.shvetsov@cern.ch

Operational Experience on Current detectors / 58

Operational Experience on tracker detectors in ALICE experiment

Corresponding Author: luca.barioglio@cern.ch

33

Operational experience with the current tracker in ALICE

Author: Luca Barioglio¹

¹ *Universita e INFN Torino (IT)*

Corresponding Author: luca.barioglio@cern.ch

ALICE (A Large Ion Collider Experiment) is a general purpose heavy-ion experiment, designed for the study of strongly-interacting matter at the extreme energy densities that characterise Pb-Pb collisions at the CERN LHC. At such energy, the formation of the Quark-Gluon Plasma (QGP), a deconfined phase of matter, is expected.

The innermost detector of ALICE is the Inner Tracking System (ITS). The ITS consists of six cylindrical layers of silicon detectors based on different technologies: two inner layers with pixel sensors (Silicon Pixel Detector), two intermediate layers with drift sensors (Silicon Drift Detector), two outer layers with strip sensors (Silicon Strip Detector).

The ITS is used for the reconstruction of primary and secondary vertices, for particle tracking, for a precise determination of the impact parameter and for particle identification at low-momentum.

In this report, after a brief description of the three sub-detectors, the operational experience with the ITS during Run2 is summarised, describing the status and the performance of the detector.

Fast timing technologies / 82

Particles tracking at fluences above 1E16 n/cm2

Corresponding Author: cartiglia@to.infn.it

5

Particles tracking at fluences above 1E16 n/cm2

Authors: Nicolo Cartiglia¹ ; Hartmut Sadrozinski² ; Abraham Seiden³

¹ *INFN Torino (IT)*

² *SCIPP, UC santa Cruz*

³ *University of California, Santa Cruz (US)*

Corresponding Authors: cartiglia@to.infn.it, hartmut@scipp.ucsc.edu, abraham.seiden@cern.ch

In this talk, the possibility of using very thin Low Gain Avalanche Diodes (LGAD) (~ 25µm thick) as tracking detector at future hadron colliders, where particle fluence will be above 1·10¹⁶neq/cm², will be explored. In the present design, silicon sensors at the High-Luminosity LHC will be 100-200µm thick, generating, before irradiation, signals of 1-2 fC. In our talk, we will show how very thin LGAD can provide signals of the same magnitude via the interplay of gain in the gain layer and gain in the bulk up to fluences above 1·10¹⁶neq/cm²: up to fluences of 0.1-0.3·10¹⁶neq/cm², thin LGADs maintain a gain of ~ 10 while at higher fluences the increased bias voltage will trigger the onset of multiplication in the bulk, providing the same gain as previously obtained in the gain layer. Key to this idea is the possibility of a reliable, high-density LGAD design able to hold large bias voltages (~ 500V). The talk will first present in detail this idea, then show our predictions based on our simulation package Weightfield2 and show how they compare to experimental data.

22

Performance Studies of the Belle II Silicon Vertex Detector

Author: Kavita Lalwani¹

¹ *Malaviya National Institute of Technology Jaipur*

Corresponding Author: kavita.phy@mnit.ac.in

Title: Performance Studies of the Belle II Silicon Vertex Detector

Kavita Lalwani for the Belle II SVD group

The Belle II experiment at the SuperKEKB asymmetric-energy e+e- collider in KEK, Japan will operate at an instantaneous luminosity of $8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, which is about 40 times larger than that of its predecessor, Belle. It is built with the aim of collecting a huge amount of data corresponding to an integration luminosity of about 50 ab⁻¹ by 2025 for precise CP violation measurements and searches for new physics. At this high luminosity, Belle II will face harsh backgrounds. To validate the performance of the silicon vertex detector (SVD) – a key component of Belle II – at such high rate and harsh background environment, a detailed systematic performance study is essential using offline software reconstruction. In this work, correlation studies of occupancy, cluster charge and position, and signal-to-noise ratio for different cluster sizes for each SVD sensors/side are presented. These studies will help us to understand and optimize the operation parameters of SVD.

15

Performance of prototype modules of CMS outer tracker for HL-LHC in test beams

Author: Suvankar Roy Chowdhury¹

¹ *National Institute of Science Education and Research (IN)*

Corresponding Author: suvankar.roy.chowdhury@cern.ch

The LHC will enter into its high luminosity phase(HL- LHC), operating at a luminosity of $5 - 7.5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ starting from 2026. To allow CMS experiment to operate efficiently, the current silicon tracker must be replaced as it will be heavily irradiated during current LHC operations and its performance will degrade. The new silicon tracker will be radiation hard to operate over the 3000 fb^{-1} data taking foreseen for the HL-LHC period. The new tracker will be made out of specially designed detector modules with stacked sensors read out by front-end chips called CMS Binary Chip\,(CBC). The CBC will be able to correlate hits in the stacked sensors and build a short track segment called stub. The stub information will be used in the Level-1 trigger to select high p_T tracks. The performance of the 2-Strip\,(2S) modules of the proposed outer tracker in test beams will be presented.

Detectors in design and construction / 73

Pixel detector for ATLAS upgrade

Corresponding Author: matthias.hamer@cern.ch

24

Pixel detector for ATLAS upgrade

Author: Matthias Hamer¹

¹ *University of Bonn (DE)*

Corresponding Author: matthias.hamer@cern.ch

In order to meet the requirements at the High-Luminosity LHC, the ATLAS inner detector will be upgraded to an all silicon tracker, the Inner Tracker ITk, until 2025. The ITk will consist of a five layer pixel detector and a four layer strip detector.

Due to the harsh environment at the High-Luminosity LHC, the ITk pixel detector will consist of newly developed front-end electronics and sensors, namely the RD53 chip and thin n-in-p sensors. The dense tracking environment requires a higher granularity compared to the currently used pixel detector, significantly higher data transmission rates and low mass global and local supports. An overview on the resulting challenges for the mechanical design and layout, the powering and data transmission schemes, testing and operation will be given, and the current status of the ongoing developments to meet these challenges will be presented.

Detectors in design and construction / 74

Pixel detector for CMS upgrade

Corresponding Author: styliani.orfanelli@cern.ch

40

Pixel detector for CMS upgrade

Author: Stella Orfanelli¹

¹ CERN

Corresponding Author: styliani.orfanelli@cern.ch

The LHC machine upgrade program will increase the luminosity delivered to the large experiments up to $7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ in 2026, with the goal of an integrated luminosity of 3000 fb^{-1} by the end of 2037. In order to fully exploit these operating conditions and luminosity, CMS plans to build a completely new pixel detector. The Phase II pixel detector relies on highly radiation tolerant sensors and a new ASIC based on 65 nm CMOS technology. A high bandwidth readout system and a novel serial powering scheme of the pixel modules will be used to accommodate the highly demanding system needs. These prospective design choices as well as new layout geometries with acceptance extended from $|\eta| < 2.4$ to $|\eta| < 4$, will be presented along with some highlights of the R & D activities.

Workshop Summary / 52

Poster Summary

Corresponding Author: prafulla.behera@cern.ch

35

Quality control for ATLAS ITk strip sensor production

Author: Christoph Thomas Klein¹

¹ Cavendish Laboratory, University of Cambridge

Corresponding Author: ck481@cam.ac.uk

With the upgrade of the LHC to the High-Luminosity LHC (HL-LHC), scheduled to commence in 2024, the Inner Detector will be replaced with the new all-silicon ATLAS Inner Tracker (ITk) to maintain tracking performance in this high-occupancy environment and to cope with the increase of approximately a factor of ten in the integrated radiation dose. The outer four layers in the barrel and six disks in the endcap region will consist of strip modules, built with single-sided strip sensors and glued-on hybrids carrying the front-end electronics necessary for readout.

The strip sensors are manufactured as n-in-p strip sensors from high-resistivity silicon, which would allow operation even after fluences expected towards the end of the proposed lifetime of the HL-LHC. Prototypes of different sensor designs have been extensively tested electrically as well as in test-beam setups, yielding mixed results especially in terms of long-term stability. Since pre-production is scheduled to start at the end of 2019, it has become increasingly necessary to have a quality control (QC) procedure for strip sensors which can identify emerging problems with manufacturing results for single sensors or whole batches, ranging from generic electric properties to reliability of long-term operation, as well as understanding the underlying processes. An overview over the QC procedure and its results will be given as well as details about the ongoing challenges.

Radiation Hardness / 64

RD42 Status report

Corresponding Author: harris.kagan@cern.ch

Radiation Hardness / 65

RD50 Status report

Corresponding Author: gianluigi.casse@cern.ch

8

RD50 activities on radiation tolerant silicon detectors

Authors: Gianluigi Casse¹ ; RD50 collaboration²¹ *FBK and University of Liverpool (GB)*² *RD50***Corresponding Author:** gianluigi.casse@cern.ch

It is foreseen to significantly increase the luminosity of the LHC by upgrading towards the HL-LHC (High Luminosity LHC), resulting in unprecedented radiation levels, significantly beyond the limits of the silicon trackers currently employed. All-silicon central trackers are being studied in ATLAS, CMS and LHCb, with extremely radiation hard silicon sensors to be employed on the innermost layers. Within the RD50 Collaboration, a large R&D program has been underway across experimental boundaries to develop silicon sensors with sufficient radiation tolerance for HL-LHC trackers.

One research topic is to gain a deeper understanding of the connection between the macroscopic sensor properties such as radiation-induced increase of leakage current, doping concentration and trapping, and the microscopic properties at the defect level. An area of strong activity is the development of advanced sensor types like 3D silicon detectors, designed for the extreme radiation levels expected for the vertexing layers at the HL-LHC, or new sensor fabrication technologies such as High-Voltage (HV) CMOS, exploiting the wide availability of the CMOS process in the semiconductor industry at very competitive prices compared to the highly specialised foundries that normally produce particle detectors on small wafers

We will present results of several detector technologies and silicon materials at radiation levels corresponding to HL-LHC fluences. Based on these results, we will give recommendations for the silicon detectors to be used at the different radii of tracking systems in the LHC detector upgrades. In order to complement the measurements, we also perform detailed simulation studies of the sensors, e.g. device structure optimization or predictions of the electric field distributions and trapping in the silicon sensors.

Electronics and System Integration: / 112

RD53-A and RD53-B plan and status

Corresponding Author: natale.demaria@cern.ch

23

Radiation damage modeling: TCAD simulation

Author: Geetika Jain¹¹ *University of Delhi (IN)*

Corresponding Author: geetika.jain@cern.ch

The exceptional performance of the silicon sensors in the radiation environment has led to their extensive usability in high energy physics. Even so, the future experiments foresee these sensors to be exposed to higher radiation levels. Radiation induces a change in the macroscopic properties of the sensor, thus, severely affecting the sensor performance and ultimately becoming the limiting factor for its operation. With an aim to extend the radiation hardness capabilities of the silicon sensors for the future experiments there has been a growing interest in sensors with novel designs and unique characteristic of intrinsic charge multiplication.

However, it is important to understand the effect of radiation damage on these sensors, before employing them in the main detector system. The RD50 collaboration extensively employs TCAD simulation tools for an in-depth understanding and structural optimization of the newly proposed sensor technologies, complementing the measurement results. The simulation tools also provide an insight into the sensor operation both in the non-irradiated and the irradiated scenario by predicting the leakage current, full depletion voltage, charge collection, electric field, etc behavior. This has required the development of a radiation damage model within the simulation tools such that the measurements are well complemented. The details of the radiation damage modeling using two commercial TCAD tools – Silvaco and Synopsys, are discussed in this work.

Radiation Hardness / 70

Radiation damage modeling:TCAD simulation

Corresponding Author: geetika.jain@cern.ch

Radiation Hardness / 66

Radiation hardness for RD53

Corresponding Author: luis.miguel.jara.casas@cern.ch

101

Radiation hardness studies and irradiation test results of RD53A chip, a large scale chip demonstrator for pixel readout at the HL-LHC

Author: Luis Miguel Jara Casas¹

¹ CERN

Corresponding Author: luis.miguel.jara.casas@cern.ch

L.M. Jara Casasa on behalf of the RD53 collaboration
a CERN,
Geneva 23,CH-1211, Switzerland

E-mail: luis.miguel.jara.casas@cern.ch

ABSTRACT: The RD53A prototype chip is a 400x192 pixel readout integrated circuit (IC) designed to qualify the chosen 65nm CMOS technology for the development of the final production IC of the Phase-2 upgrade of ATLAS and CMS experiments at the High-Luminosity (HL) Large Hadron

Collider (LHC). This 20.0mm by 11.8mm chip has been designed in the framework of the RD53 collaboration [1], a joint effort between ATLAS and CMS communities, and it contains design variations for testing purposes, different analog front-end and digital architectures.

The harsh environment of HL-LHC including a peak luminosity of $5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$, an estimated ionizing dose (TID) of 1Grad and 1MeV neutron equivalent fluence of $2 \times 10^{16} \text{cm}^{-2}$ accumulated during their lifetime and very high rates of the order of 3GHz/cm², sets challenging requirements for the detectors of these experiments. The RD53A collaboration has made an effort to characterize the radiation effects in the 65nm CMOS technology, whose radiation tolerance properties have been investigated for analog and digital circuits with specific test chips.

The RD53A chip includes ring oscillators to characterize the radiation damage on digital circuits, and also a radiation sensor. Design techniques to overcome the radiation effects and TID test results up to 500Mrad will be reported.

KEYWORDS: Radiation damage to electronic components; Radiation-hard electronics, pixel readout chip.

References

[1] J. Christiansen and M. Garcia-Sciveres, RD Collaboration proposal: development of pixel readout integrated circuits for extreme rate and radiation, LHCC-P-006 (2013)

Fast timing technologies / 84

Radiation tolerance and time resolution of depleted CMOS sensors

Corresponding Author: vilella@hep.ph.liv.ac.uk

28

Radiation tolerance and time resolution of depleted CMOS sensors

Authors: Eva Vilella Figueras¹ ; RD50 collaboration²

¹ *University of Liverpool (GB)*

² *RD50*

Corresponding Author: vilella@hep.ph.liv.ac.uk

Depleted CMOS sensors, also known as Depleted Monolithic Active Pixel Sensors (DMAPS), are extremely attractive for particle physics experiments. As the sensing diode and readout electronics can be integrated on the same silicon substrate, DMAPS suppress the need for hybridization and this results in thin detectors with reduced production time and costs. High Resistivity (HR) substrates and High Voltage (HV) processes are used to manufacture these detectors and thus achieve high radiation tolerance and speed. Today's most performant DMAPS in HR/HV-CMOS are 50 μm thick, with $5 \times 10^{15} \text{ 1MeV n}_{\text{eq}}/\text{cm}^2$ radiation tolerance and 15 ns time resolution. These detectors have been adopted as the sensor technology of choice for the Mu3e experiment and are under consideration for the planned Phase-II Upgrade of the ATLAS experiment at the Large Hadron Collider (LHC).

In spite of the major improvements demonstrated by DMAPS, further research to achieve even more performant sensors is needed to realize the full potential of the extremely challenging particle physics experiments planned and foreseen for the future. In this context, the CERN-RD50 collaboration has identified the study of depleted CMOS sensors as one of its main priorities. Key areas explored within RD50 focus on radiation tolerance and time resolution. Measurements done within the collaboration show that thin DMAPS with backplane processing to apply the HV to the substrate

present improved performance after irradiation. Apart from this, and following from work in the wider community, specific developments within RD50 have already started with the prototyping of DMAPS in the 150 nm HV-CMOS technology from LFoundry S.r.l. A large area demonstrator with several matrices of pixels is currently being designed. Amongst other features, the matrices implement novel methods to improve the time resolution of the sensor to ideally the sub-nanosecond range. Targeting a radiation tolerance beyond 10^{16} 1MeV n_{eq}/cm^2 , an extensive irradiation campaign is foreseen to evaluate the performance of the demonstrator manufactured in different substrate resistivities with standard topside and post-processed backside biasing. Further details will be provided during the workshop.

42

Results and perspectives from RD53 on the Next Generation Read-out Chips for HL-LHC silicon pixel detector phase 2 upgrades

Author: Lino Demaria¹

¹ *Universita e INFN Torino (IT)*

Corresponding Author: natale.demaria@cern.ch

The Phase 2 upgrades of silicon pixel detectors at HL-LHC experiments feature extreme requirements, such as: 50um x50um pixels, high rate (3 GHzx/cm²) unprecedented radiation levels (1 Grad), high readout speed, serial powering. As a consequence a new readout chip is required

In this framework the RD53 collaboration has designed RD53A, a large scale chip demonstrator designed in 65 nm CMOS technology, integrating a matrix of 400x192 pixels. It features design variations in the analog and digital pixel matrix for testing purposes.

The chip size is 20.0mm by 11.8 mm. RD53A is not intended to be a production IC for use in an experiment, and contains design variations for testing purposes, making the pixel matrix non-uniform. The 400x192 pixel matrix features in fact three flavors of analog front-ends and two digital readout architectures. The pixel matrix is built up of 8 by 8 pixel cores. In addition the 64 front-ends within a core are organized in 16 so-called analog islands with 4 fronts ends each, which are embedded in a flat digital synthesized sea.

RD53A has been submitted in August 2017 and is now undergoing a comprehensive characterization phase.

An overview of RD53A building blocks will be given together with comprehensive test results on single chips and modules. Test results on single chips including performance qualification for the three analog front-ends will be presented, together with tests on modules of RD53A bonded with sensors. In addition, the ongoing activities in view of the final chip implementation for the experiments will be outlined

Fast timing technologies / 95

Results and perspectives from RD53 on the Next Generation Read-out Chips for HL-LHC silicon pixel detector phase 2 upgrades

Corresponding Author: natale.demaria@cern.ch

Electronics and System Integration: / 110

Review on depleted CMOS

Corresponding Author: thanushan.kugathan@cern.ch

Fast timing technologies / 96

Review on depleted CMOS

Corresponding Author: thanushan.kugathan@cern.ch

104

Review on depleted CMOS

Author: Thanushan Kugathan¹

¹ CERN

Corresponding Author: thanushan.kugathan@cern.ch

Monolithic active pixel sensors (MAPS) integrate both sensor matrix and readout circuitry in one piece of silicon. Pixel sensors in commercial CMOS technologies receive increasing interest for vertex detectors. They have advantages in detector assembly, production cost, and other benefits like lower material and higher granularity. Used for the first time in the STAR experiment, adopted for the ALICE experiment, they are being considered for future detectors, like the ATLAS HL-LHC upgrade, FCC and CLIC. The most aggressive applications require full depletion in the sensing volume where charge collection by drift improves timing and radiation tolerance to high-intensity hadron fluences. This talk addresses the improvements and challenges of depleted CMOS with insights on sensor and circuit design.

Fast timing technologies / 83

SiPM for timing

Corresponding Author: rok.pestotnik@cern.ch

Detectors in design and construction / 79

Silicon tracker detector for the ALICE upgrade

Corresponding Author: serhiy.senyukov@cern.ch

37

Silicon tracker detector for the ALICE upgrade

Author: Serhiy Senyukov¹

¹ *Centre National de la Recherche Scientifique (FR)*

Corresponding Author: serhiy.senyukov@cern.ch

ALICE is a general-purpose experiment at CERN dedicated to the study of nucleus-nucleus collisions at the LHC.

In 2019-20 during the second LHC shutdown (LS2) the ALICE detector will be upgraded in order to improve

its capability of studying rare probes like charmed and beauty mesons and baryons. One of the key parts of this upgrade

is the replacement of the whole Inner Tracking System (ITS) with the new silicon tracker composed of 7 layers of CMOS Pixel Sensors (CPS).

CPS allow for higher pixel granularity and lower material budget with respect to hybrid pixel sensors used in LHC experiments so far.

Therefore it becomes possible to increase the pointing resolution of the detector by at least a factor of 3 with respect to the present ITS.

In this contribution we will describe the detector design and the current production status.

20

Spatial Resolution of the Belle II Silicon Vertex Detector

Author: Soumen Halder¹

¹ *Research Scholar*

Corresponding Author: soumen.halder@tifr.res.in

The Belle II experiment at the SuperKEKB collider in Japan will search for new sources of CP violation as well as probe new physics by studying the suppressed decays of beauty and charm mesons. In these pursuits, the spatial resolution of the silicon vertex detector (SVD) of the experiment will play a key role. We dwell on the studies undertaken towards extracting the SVD spatial resolution based on simulated and commissioning data, and how all these might help improving the SVD reconstruction software. We also provide an insight into the working of the latest version of the SVD software.

Operational Experience on Current detectors / 60

Status of AFP

Corresponding Author: paula.agnieszka.swierska@cern.ch

13

Status of AFP

Author: Paula Agnieszka Erland¹

¹ *Institute of Nuclear Physics PAN (PL)*

Corresponding Author: paula.agnieszka.swierska@cern.ch

Located at the Large Hadron Collider (LHC), the ATLAS experiment has been designed with the goal of measuring the products of proton-proton collisions. ATLAS has full azimuthal angle coverage over a large range in pseudorapidity (from -4.2 to +4.2). However, forward particles, with larger absolute rapidities, escape detection down into the beam pipe. In particular, forward protons produced in central diffraction and double photon exchange processes, that have suffered energy losses between 2% and 15%, are not measured and cannot be studied by ATLAS. The solution is to install dedicated devices, called Roman pots, which can detect such scattered protons.

The ATLAS Forward Proton (AFP) detector consists of a total of four detector stations, two per side of ATLAS located at 205 m and 217 m from the ATLAS interaction point. Each detector station houses a 4-layer Silicon pixel Tracker (SiT) and the stations at 217 m also house Time of Flight (ToF) detectors. The SiT measures proton position with a precision up to 6 μm , allowing a precise reconstruction of the proton kinematics. The ToF detectors consist of 16 L-shaped Quartz Cerenkov bars read out by ultra-fast photomultipliers. The ToF serves to reduce the single-diffraction background by determining the primary vertex of the two forward protons from their arrival times.

After brief introduction of the physics of interest, the main features of the AFP detector (i.e. the movement, cooling, vacuum, readout systems) will be presented. The main focus will be on the performance of the detector system: detector resolution, effects of radiation damage, features of operation in the high pile-up environment.

Operational Experience on Current detectors / 61

Status of CT-PPS

Corresponding Author: margherita.obertino@cern.ch

6

Status of CT-PPS

Author: Maria Margherita Obertino¹

¹ *Universita e INFN Torino (IT)*

Corresponding Author: margherita.obertino@cern.ch

The PPS (Precision Proton Spectrometer) system consists of tracking and timing detectors installed along the LHC beam line between 210 and 220 m from the interaction point on both sides of the CMS experiment. The aim of the apparatus is to measure with high precision the position, direction and time-of-flight of protons which emerge intact from the pp collision. Fully integrated in the CMS data acquisition system, PPS has taken data at high luminosity during the years of the LHC-Run2 (2016-2018), with slightly different detector configurations. The current apparatus consists of 4 tracking stations (two per side) with 6 planes of 3D pixel sensors each, plus 2 timing stations (one per side), instrumented with 2 single and 2 double diamond planes each. In this presentation commissioning, operation and performance of PPS are discussed with focus on the 2018 data taking period.

Applications of Silicon Detectors in high /low background environment / 72

Status of HgCAL in CMS upgrade

Corresponding Author: shashikant.dugad@cern.ch

Electronics and System Integration: / 111

Status of SoI Sensors

Corresponding Author: hara@hep.px.tsukuba.ac.jp

Applications of Silicon Detectors in high /low background environment / 71

Status of pnCCDs

Corresponding Author: fls@hll.mpg.de

45

Status of pnCCDs

Author: Florian Schopper¹

¹ *Halbleiterlabor der Max-Planck-Gesellschaft*

Corresponding Author: fls@hll.mpg.de

pnCCDs are CCD devices which use pn-diodes instead of MOS-registers to generate the electric field that drives charges along the channel.

Therefore they are radiation tolerant and can transfer at high speed.

We show applications for X-ray imaging, either as integrating devices or as spectroscopic single event counters with the possibility of position interpolation.

New developments for faster transfer and large signal storage capability are discussed and simulation results

for a combination of CCD transfer with DEPFET readout nodes are shown.

Future Collider Experiments / 106

Status of silicon detector R&D at CLIC

Corresponding Author: magdalena.munker@cern.ch

Electronics and System Integration: / 86

Status of silicon detector R&D at CLIC

Corresponding Author: magdalena.munker@cern.ch

Status of silicon detector R&D at CLIC

3

Status of silicon detector R&D at CLIC

Author: Ruth Magdalena Munker¹

¹ *University of Bonn (DE)*

Corresponding Author: magdalena.munker@cern.ch

CLIC is an option for a linear electron positron collider in the post LHC era at CERN, aiming at a centre of mass energy of up to 3 TeV. Challenging requirements are imposed on the CLIC all-silicon vertex and tracking system to perform high precision measurements in an environment with high rates of beam-induced background particles. A spatial resolution of a few micrometers and a material budget down to 0.2% radiation length per vertex-detector layer have to be achieved together with a few nanoseconds time stamping accuracy. These requirements are addressed with innovative technologies in an ambitious detector R&D programme, comprising hardware developments as well as detailed device and Monte Carlo simulations. Various fine pitch hybrid silicon pixel detector technologies are under investigation for the CLIC vertex detector. The CLICpix and CLICpix2 readout ASICs with 25 micron pixel pitch have been produced in a 65 nm commercial CMOS process and bump-bonded to planar active edge sensors as well as capacitively coupled to High-Voltage CMOS (HV-CMOS) sensors. Monolithic silicon tracking detectors are foreseen for the large surface (~140 square meters) CLIC tracker. Fully monolithic prototypes are currently under development in High-Resistivity CMOS (HR-CMOS), HV-CMOS and Silicon on Insulator (SOI) technologies. This talk presents an overview of the CLIC silicon detector R&D programme, focussing on recent test-beam and simulation results.

Operational Experience on Current detectors / 63

Status of silicon tracker in NA62

Corresponding Author: mathieu.perrin-terrin@cern.ch

48

Status of silicon tracker in NA62

Author: Mathieu Perrin-Terrin¹

¹ *Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France*

Corresponding Author: mathieu.perrin-terrin@cern.ch

The Gigatracker is the NA62 beam tracker. It is made of three 63.1 mm × 29.3 mm stations of 300 μm × 300 μm hybrid silicon pixel detectors installed in vacuum (~ 10⁻⁶ mbar).

The beam particles, flowing at 750 MHz, are traced in 4-dimensions by means of time-stamping pixels with a design resolution of 200 ps. This performance has to be maintained despite the beam irradiation amounting to a yearly fluence of 2 × 10¹⁴ 1 MeV eq. n/cm².

The detector material minimization is paramount, as the detector faces the full beam. The station material budget is reduced to 0.5% X₀ by using (HEP world first) microchannels cooling.

We will describe the detector design and performances during the NA62 runs.

Status of the Tracker Design for FCChh

Corresponding Author: estel.perez.codina@cern.ch

Electronics and System Integration: / 87

Status of the Tracker Design for FCChh

Corresponding Author: estel.perez.codina@cern.ch

14

Status of the Tracker Design for FCChh

Author: Estel Perez Codina¹

¹ CERN

Corresponding Author: estel.perez.codina@cern.ch

The $\sqrt{s}=100$ TeV proton-proton collider, FCC-hh, is a core part of the Future Circular Collider project. The conceptual design of a suitable detector for FCC-hh is an integral part of this ongoing effort.

Such a detector should be able to operate under luminosities of up to $3 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, and pile-up conditions of up to ~ 1000 interactions per bunch crossing. In addition, the physics program includes signatures with highly boosted objects that create jets with very high track density and displaced secondary vertices far away from the interaction point. These conditions make particle tracking, vertex identification, and flavor tagging extremely challenging.

This contribution reviews the general ideas and requirements that drive the current tracker and vertex detector design for FCC-hh, like the detector granularity, material budget and pattern recognition. A special emphasis will be made on the reconstruction of boosted objects and the capability to identify heavy flavor jets.

Future Collider Experiments / 108

Status of tracking detectors at ILC

Corresponding Author: gagan.bihari.mohanty@cern.ch

Electronics and System Integration: / 88

Status of tracking detectors at ILC

Corresponding Author: gagan.bihari.mohanty@cern.ch

47

Status of tracking detectors at ILC

Author: Gagan Mohanty¹

¹ *Tata Inst. of Fundamental Research (IN)*

Corresponding Author: gagan.bihari.mohanty@cern.ch

Precision measurements of the properties of the Higgs boson, discovered by the ATLAS and CMS experiments of the LHC, and the top quark, the heaviest known elementary particle, are among the main physics goals for experiments at the proposed international linear collider (ILC). These measurements must reach an unprecedented level of precision in order to allow us to decipher the next fundamental layer of physics, called new physics. The vertex and tracking detectors of the ILC experiments will be a key towards accomplishing the ambitious physics programs of the latter. We discuss the design requirements of these state-of-the-art detector systems, driven by stringent physics and experimental constraints of the ILC.

Radiation Hardness / 69

Study of damages induced on ATLAS silicon by fast extracted and intense proton beam irradiation

Corresponding Author: claudia.bertella@cern.ch

16

Study of damages induced on ATLAS silicon by fast extracted and intense proton beam irradiation

Authors: Claudia Gemme¹; Alessandro Lapertosa²; Claudia Bertella³; Mercedes Minano Moya⁴; Carlos Escobar Ibañez⁵; Serge Katunin⁶; Antonio Sbrizzi⁷

¹ *Universita degli Studi di Genova Dipart. di Fisica*

² *INFN e Universita Genova (IT)*

³ *Chinese Academy of Sciences (CN)*

⁴ *Instituto de Física Corpuscular (CSIC-UV)*

⁵ *Instituto de Física Corpuscular (IFIC) - CSIC/UV*

⁶ *Petersburg Nuclear Physics Institut (RU)*

⁷ *Universita e INFN, Bologna (IT)*

Corresponding Authors: alessandro.lapertosa@cern.ch, mercedes.minano@cern.ch, antonio.sbrizzi@cern.ch, claudia.bertella@cern.ch, sergey.katunin@cern.ch, carlos.escobar.ibanez@cern.ch, gemmec@ge.infn.it

The ATLAS silicon tracker detectors are designed to sustain high dose integrated over several years of operation. This very substantial radiation hardness should also favour the survival of the detector in case of accidental beam losses.

An experiment performed in 2006 showed that ATLAS pixel detector modules (silicon planar hybridly coupled with FE-I3 electronics) could survive to beam losses up to 1.5 · 10¹⁰ protons/cm² in a single bunch with minimal or no deterioration of performance.

The upgrade of LHC to even higher luminosity (HL-LHC) calls for a new test of these properties.

Two test beam campaigns have been done in 2017 and 2018 at the High-Radiation to Materials (Hi-RadMat) Facility of the CERN Super Proton Synchrotron in order to establish for the first time the damage threshold of different types of ATLAS IBL pixel and ITK strip detectors under very intense proton beam irradiation.

18

System design challenges for CO₂ evaporative cooling in tracking detectors

Author: Paola Tropea¹

¹ *CERN*

Corresponding Author: paola.tropea@cern.ch

CO₂ evaporative cooling has become one of the most popular thermal management technologies for silicon detectors to be operated at low temperature. At LHC, this solution is already in use on the LHCb Velo, the ATLAS IBL and the CMS Phase I Pixel. The LHCb Velo upgrade and the UT detectors will be cooled in the same way as of 2019, as well as ATLAS and CMS upgraded tracking and vertexing detectors for the HL-LHC (2025).

In order to fully exploit the heat removal capacity which can be achieved with carbon dioxide in evaporative mode, the cooling system needs a very careful design, combining the process, the transfer lines and the on-detector evaporators.

This presentation discusses the challenges for the design of an optimised CO₂ cooling system, including the mechanics, the thermal interfaces and the process instrumentation for controls and monitoring. Examples of presently adopted solutions are given, together with their limits and the needed further development in order to achieve reliable systems of much higher cooling power as in HL-LHC detectors.

Future Collider Experiments / 49

System design challenges for CO₂ evaporative cooling in tracking detectors

Corresponding Author: paola.tropea@cern.ch

17

The Belle II PXD

Author: Varghese Babu¹

¹ *DESY*

Corresponding Author: varghese.babu@desy.de

The Belle II experiment will be the next generation B-factory, and will operate at an peak instantaneous luminosity, $8.0 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, 40 times higher than its predecessor, Belle, allowing for precision measurements of the standard model. At its center will lie two layers of DEPFET based pixel detectors, each 75 microns thick to minimize multiple scattering of charged particles and designed to operate at a high radiation environment. Together with four layers of silicon strip detectors, it is expected to provide a resolution of 15 microns for charged particle

vertexing, which will be crucial for time-dependent measurements of CP violation. We provide an overview of the Belle II PXD in this poster.

Detectors in design and construction / 80

The CMS Outer Tracker Upgrade for the High Luminosity LHC

Corresponding Author: anirban.saha@cern.ch

9

The CMS Outer Tracker Upgrade for the High Luminosity LHC

Authors: Anirban Saha¹ ; Anirban Saha^{None}

¹ *Florida State University (US)*

Corresponding Author: anirban.saha@cern.ch

The era of High Luminosity Large Hadron Collider will pose unprecedented challenges for detector design and operation. The planned luminosity of the upgraded machine is $5 - 7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, reaching an integrated luminosity of 3000-4500 fb^{-1} by the end of 2039. CMS Tracker detector will have to be replaced in order to fully exploit the delivered luminosity and cope with the demanding operating conditions. The new detector will provide robust tracking as well as input for the first level trigger. This report is focusing on the replacement of the CMS Outer Tracker system, describing new layout and technological choices together with some highlights of research and development activities.

105

The LHCb VELO Upgrade

Author: Deepanwita Dutta¹

¹ *University of Manchester (GB)*

Corresponding Author: deepanwita.dutta@cern.ch

The LHCb experiment is a forward spectrometer experiment dedicated primarily to study CP violation and rare decays of beauty and charm hadrons. The LHCb experiment will be upgraded to a trigger-less system reading out data at 40 MHz event rate. To cope with the higher data rates and increased occupancy, the detectors including the Vertex Locator (VELO) need to be upgraded. The VELO performs high precision track and vertex reconstruction. The upgraded detectors will be installed during the upcoming LHC long shutdown2 (LS2), currently scheduled to start at 2019-2020. The upgraded VELO will be a hybrid pixel detector having pixels of dimensions $55 \times 55 \mu\text{m}^2$. Data from the pixel sensors will be read-out via VeloPix ASICs and transmitted through high speed serial links to the off-detector electronics. Low mass evaporative CO₂ cooling will be used with the coolant circulating within etched microchannels in the silicon substrate. The upgraded VELO will provide fast pattern recognition and track reconstruction to the software trigger. In this talk, I will discuss the design requirements, recent R&D results and the current status of the VELO upgrade.

Radiation Hardness / 67**The Malta CMOS pixel detector prototype for the ATLAS Pixel ITK****Corresponding Author:** abhishek.sharma@cern.ch

1

The Malta CMOS pixel detector prototype for the ATLAS Pixel ITK**Author:** Abhishek Sharma¹**Co-authors:** Lluis Simon Argemi²; Ignacio Asensi Tortajada³; Ivan Berdalovic⁴; Daniela Bortoletto¹; Roberto Cardella⁴; Florian Dachs⁵; Valerio Dao⁴; Tomasz Hemperek⁶; Bojan Hiti⁷; Thanushan Kugathanan⁴; Cesar Augusto Marin Tobon⁴; Konstantinos Moustakas⁶; Heinz Pernegger⁴; Petra Riedler⁴; Piotr Rymaszewski⁶; Christian Riegel⁸; Enrico Junior Schioppa⁴; Walter Snoeys⁴; Carlos Solans Sanchez⁴; Tianyang Wang⁶; Norbert Vermes⁶¹ *University of Oxford (GB)*² *University of Glasgow (GB)*³ *Univ. of Valencia and CSIC (ES)*⁴ *CERN*⁵ *Vienna University of Technology (AT)*⁶ *University of Bonn (DE)*⁷ *Jozef Stefan Institute (SI)*⁸ *Bergische Universitaet Wuppertal (DE)***Corresponding Authors:** konstantinos.moustakas@cern.ch, ignacio.asensi@cern.ch, tianyang.wang@cern.ch, christian.riegel@cern.ch, heinz.pernegger@cern.ch, verm@uni-bonn.de, petra.riedler@cern.ch, enrico.junior.schioppa@cern.ch, valerio.dao@cern.ch, thanushan.kugathanan@cern.ch, rymaszewski@physik.uni-bonn.de, walter.snoeys@cern.ch, florian.dachs@cern.ch, cesar.augusto.marin.tobon@cern.ch, abhishek.sharma@cern.ch, daniela.bortoletto@cern.ch, hemperek@physik.uni-bonn.de, lluis.simon.argemi@cern.ch, bojan.hiti@cern.ch, carlos.solans@cern.ch, ivan.berdalovic@cern.ch, roberto.calogero.cardella@cern.ch

The ATLAS experiment is planning a major upgrade of its tracking detectors, both strip and pixel, to take full advantage of the High Luminosity LHC. A novel Monolithic Active Pixel Sensor based on 180 nm TowerJazz CMOS imaging technology, dubbed MALTA, has been designed to meet the radiation hardness requirements (1.5×10^{15} 1 MeV neq/cm²) of the outer barrel layers of the ITK Pixel detector. MALTA combines low noise (ENC < 20 e⁻) and low power operation (1 μ W/pixel) with a fast signal response (25 ns bunch crossing) in small pixel size (36.4x36.4 μ m²), with a novel high-speed asynchronous readout architecture to cope with the high hit-rates expected at HL-LHC. Extensive lab testing and characterisation in particle beam tests have been conducted on this design and compared with previous prototypes of the same technology. An overview of the sensor technology and readout architecture are presented along with the preliminary results from laboratory tests, radioactive source tests and beam tests.

Operational Experience on Current detectors / 62**The STAR Heavy Flavor Tracker: Embedding Simulations into a High Multiplicity Environment****Corresponding Author:** jwebb@bnl.gov

39

The STAR Heavy Flavor Tracker: Embedding Simulations into a High Multiplicity Environment

Authors: Gene Van Buren¹ ; Jason Webb¹ ; Jérôme Lauret¹ ; Sooraj Radhakrishnan² ; Xin Dong²

¹ *Brookhaven National Laboratory*

² *Lawrence Berkeley National Laboratory*

Corresponding Author: jwebb@bnl.gov

The STAR Heavy Flavor Tracker (HFT) has enabled a rich physics program, providing important insights into heavy quark behavior in heavy ion collisions. Acquiring data during the 2014 through 2016 runs at the Relativistic Heavy Ion Collider (RHIC), the HFT consisted of four layers of precision silicon sensors, including the first application of the thin Monolithic Active Pixel Sensors (MAPS) technology in a collider environment: the STAR Pixel detector. Used in concert with the Time Projection Chamber (TPC), the HFT enables the reconstruction and topological identification of tracks arising from charmed hadron decays. The ultimate understanding of the detector efficiency and resolution demands high quality simulations, accounting for the precise positioning of the sensors, and the detailed response of the detectors and electronics to the incident tracks. The background environment presents additional challenges, including significant contributions from pileup events accumulated during the long integration times of the tracking detectors, and complicated by the large flux through the first pixel layer of low-momentum electrons from ultra-peripheral collisions. We will discuss how STAR has addressed realistic simulations (aka embedding) for efficiency corrections, and will show how the careful consideration of misalignment of precision detectors and calibration uncertainties results in detailed reproduction of basic observables, such as track projection to the primary vertex. We will further summarize the experience and lessons learned in applying these techniques to heavy-flavor simulations and discuss recent results.

21

Timepix3 performance in pulsed power operation

Authors: Estel Perez Codina¹ ; Daniel Hynds²

¹ *CERN*

² *University of Glasgow (GB)*

Corresponding Authors: daniel.hynds@cern.ch, estel.perez.codina@cern.ch

The physics aims at the proposed CLIC linear e^+e^- collider pose challenging requirements on the performance of the detector system. In particular for the vertex detector the principal challenge is building an ultra-low mass ($\sim 0.2\% X_0$ per layer) detector that can provide a point resolution of a few μm as well as ~ 10 ns time stamping capabilities.

To reach such low material budget, CLIC uses an air-flow cooling system in the inner vertex region. This requires very low power dissipation, which is achieved by exploiting CLIC's low duty cycle ($\sim 0.001\%$) and beam structure, allowing pulsed power operation of the pixel detector.

Timepix3 is the first readout chip to include power pulsing features, such as, in the analog domain, allowing to switch dynamically between nominal power and shutdown modes and, in the digital domain, gating the clock of the pixel matrix.

This contribution reports the performance of the TimePix3 chip operating in pulsed power, in terms of power saving, detection efficiency and noise performance. Measurements were performed in a beam test taking as reference tracks provided by a telescope, as well as in the laboratory using a radioactive source.

Tracking and vertexing in ATLAS experiment

Corresponding Author: goetz.gaycken@cern.ch

Tracking and vertexing / 93

Tracking and vertexing in BELLE II

Corresponding Author: bscavino@uni-mainz.de

38

Tracking and vertexing in BELLE II

Author: Bianca Scavino¹

¹ *Universität Mainz*

Corresponding Author: bscavino@uni-mainz.de

Belle II is a next generation B-factory experiment at the SuperKEKB collider. In early 2019 the fully operational detector will start taking data. The goal is to collect a statistics 50 times larger than the one collected by its predecessor Belle, namely an integrated luminosity of 50 ab^{-1} .

Belle II is designed for detecting and reconstructing particle trajectories for transverse momenta exceeding $50 \text{ MeV}/c$ while providing excellent momentum resolution over a wide range of momentum.

In this contribution, the tracking and vertexing algorithms implemented in the Belle II software framework are presented, together with the performances on simulated $\Upsilon(4S) \rightarrow B\bar{B}$ events and on data collected during the detector commissioning phase.

102

Tracking and vertexing in CMS experiment

Author: Nicola De Filippis¹

¹ *Politecnico/INFN Bari (IT) and LPC-Fermilab (US)*

Corresponding Author: nicola.de.filippis@cern.ch

Track and vertex reconstruction in the CMS detector use the information from the silicon pixel and the silicon strip detectors. The track and vertex finding and fitting algorithms are based on the Kalman filter approach. Difficulties arise in the context of standard LHC events with a high density of charged particles, where the rate of fake combinatorial tracks is very large for low p_T tracks, and nuclear interactions in the tracker material reduce the tracking efficiency for charged hadrons. The performance of track and vertex reconstruction derived with 2016 and 2017 data collected by CMS are presented. Recent improvements with the CMS tracking detectors are described with emphasis of the impact of the new pixel detector, able to sustain larger instantaneous luminosities. Prospects for the tracker upgrade for Phase II high luminosity scenario of the LHC are also described.

Tracking and vertexing / 89

Tracking and vertexing in CMS experiment

Corresponding Author: nicola.de.filippis@cern.ch

Tracking and vertexing / 92

Tracking and vertexing in LHCb

Corresponding Author: renata.kopecna@cern.ch

27

Tracking and vertexing in LHCb

Author: Renata Kopecna¹

¹ *Ruprecht Karls Universitaet Heidelberg (DE)*

Corresponding Author: renata.kopecna@cern.ch

The LHCb detector is a multipurpose single-arm forward spectrometer. The main goal of its design is heavy flavor physics, covering large range of topics such as rare beauty and charm decays, CP violation and dark matter searches.

It's excellent resolution and reconstruction efficiency in the rapidity region of $2 < \eta < 5$ makes much broader physics program possible, including searches for new particles or heavy-ion collision studies.

LHCb tracking system consists of the Vertex Locator (VELO), a high granularity silicon-strip vertex detector, the Tracker Turicensis (TT), a silicon strip detector upstream of the magnet, and three Tracking Stations (T-Stations), consisting of the Inner Tracker (IT) in the inner area and the Outer Tracker (OT) in the outer area. The IT is a silicon strip detector, while the OT is made of straw drift tubes. In the most upstream region, five rectangular muon stations, based on the multi wire proportional chamber technology, are placed. This design is very heterogeneous and requires a complex system of charged particle reconstruction algorithms. LHCb has set up a real-time fully automated alignment systems to ensure offline data precision already at the online data level.

In this talk, the alignment, the track reconstruction and primary vertex reconstruction will be presented, with focus on the overall performance. Several data-driven studies were developed in order to describe the tracking efficiencies with outstanding precision. Such study is an important part of all analyses, crucial for any high-precision measurements. While most methods are based on clean muon samples, due to recent hints of lepton universality violation, method for the evaluation of the efficiency dedicated to electrons is being developed. Moreover, LHCb's unique trigger setup allows prompt access to such muon and electron samples. Such robust techniques with fast accessibility to data does not only directly impact the quality of the LHCb results, but also serve as a basis for the upcoming upgrade.

36

Tracking and vertexing in the ALICE experiment at the LHC

Author: Iouri Belikov¹

¹ *Centre National de la Recherche Scientifique (FR)*

Corresponding Author: jouri.belikov@cern.ch

In this talk we will give an overview of the methods for track and vertex reconstruction being used in the ALICE experiment at the LHC.

In response to the challenge of high charged-particle multiplicities (up to $dN/dy \sim 2000$) and relative softness of particle momentum spectra observed in Pb-Pb collisions, ALICE has implemented a few specific algorithmic approaches allowing for substantial improvements in the reconstruction efficiency and precision.

With the coming upgrade of the main detectors, the experiment is going to increase its event-recording rate by about two orders of magnitude.

The differences in the reconstruction strategy between the current and future data taking scenarios, in particular the track-to-vertex association under conditions of continuous readout, will be discussed in this presentation as well.

103

Tracking and vertexing using the ATLAS detector

Author: Goetz Gaycken¹

¹ *University of Bonn (DE)*

Corresponding Author: goetz.gaycken@cern.ch

Run-2 at the LHC is nearing its end, and has already delivered an integrated luminosity of nearly 150 fb^{-1} to ATLAS where the instantaneous luminosity exceeded $2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$.

The high instantaneous luminosity challenged the ATLAS track and vertex reconstruction with a peak number of $O(60)$ simultaneous interactions. Effects from radiation damage also start to become visible.

The current performance and evolution of the ATLAS track and vertex reconstruction will be discussed, and prospects for run-3 will be

Tracking and vertexing / 91

Tracking and vertexing in the ALICE experiment at the LHC

Corresponding Author: iouri.belikov@cern.ch

Fast timing technologies / 99

Wireless data transmission

Corresponding Author: richard.brenner@cern.ch

Workshop Summary / 53

Workshop Summary

Corresponding Author: frank.hartmann@cern.ch

46

experience in operating the silicon detectors

Author: David Hutchcroft¹

¹ *University of Liverpool (GB)*

Corresponding Author: david.hutchcroft@cern.ch

The LHCb silicon detectors were designed to tolerate the very high radiation dose expected, at as little as 8mm from the LHC collisions. The experience in monitoring the detectors and how the the HV, cooling and simulation of the system had to be updated will be explored. The data collected and how it was used to understand and optimise the detector and what lessons were learned about that will be discussed.