



CEPC Silicon Tracker

硅径迹探测器

徐子骏 (xuzj@ihep.ac.cn) 中国科学院高能物理研究所 on behalf of the CEPC Silicon Tracker Group

第三届半导体辐射探测器研讨会, 合肥, 2023年5月12日

Outline

- Introduction
- R&D Status:
 - HVCMOS Sensor
 - ATLASPix3 results
 - QuadModule
 - stave demo
 - mechannical design
- Infrastructure, expertise

Introduction

- CEPC requires a high-resolution and low-material tracking system
- Large area of silicon!
 - $> 70 \text{ m}^2$ for baseline design: Silicon + TPC
 - ~ 140 m² for Full Silicon Tracker
- CMOS is the promising technology for cost effectiveness and performance







by Frank Hartman

Baseline design

Full Silicon Tracker

CMOS Tracker Collaborators

Australia

• University of Adelaide

China

- Harbin Institute of Technology
- Hunan University
- Institute of High Energy Physics, CAS
- Northwestern Polytechnical University
- Shandong University
- T. D. Lee Institute Shanghai Jiao Tong University
- University of Science and Technology of China
- University of South China
- Zhejiang University

• Germany

• Karlsruhe Institute für Technologie

Italy

- INFN Sezione di Milano, Università degli Studi di Milano e Università degli Studi dell'Insubria
- INFN Sezione die Pisa e Università di Pisa
- INFN Sezione di Torino e Università degli Studi di Torino

UK UK

- Lancaster University
- Queen Mary University of London
- STFC Daresbury Laboratory
- STFC Rutherford Appleton Laboratory
- University of Bristol
- University of Edinburg
- University of Liverpool
- University of Oxford
- University of Sheffield
- University of Warwick

HVCMOS sensors

- HVCMOS sensors features large charge collection electrode encapsulating pixel electronics
- Achieving HV bias (> 50 V) without process modification
- => Cost-effective solution for large area detectors
- Intrinsic radiation hardness
 - Verified by radiation tests up to $10^{15} n_{eq}/cm^2$
- Large capacitance due to the large electrode
 - Causing increased noise and power consumption



sensor candidate: ATLASPix3

- ATLASPix3 features
 - TSI 180nm HV process on 200 Ωcm substrate
 - Pixel size $50\times150~\mu m^2$
 - 132 columns × 372 rows (20.2 × 21 mm² chip)
 - Each pixel has 7-bit TOT + 10-bit timestamp
 - Continuous / triggered readout with 8b10b / 64b66b coding
 - Power consumption ~160 mW/cm².





Time-Over-Threshold: proxy of signal amplitude



IEEE SSC Vol. 56, No.8, 2021



ATLASPix3 tests with radioactive sources

• ATLASPix3 responses to cosmic ray or various radioactive sources are observed at different sites



Quad module

- Readout unit based on 4 ATLASPix3 chips with common power and data readout
- Flex designed, assembled and tested by INFN Milan
 - Shared service by common power connections and configuration lines
- Readout using GECCO system with dedicated adapter card and data flex





X-ray scan 5 min with 15k-34k hits/s



Test setup with GECCO

Beam test

- Testbeam at DESY in April 2022 using electron beam up to 6 GeV
 - Two standalone telescope systems in interleaved configuration
 - Each equipped with 4 chips
 - Quad module located downstream

L.Meng @ VERTEX2022 R. Zanzottera, E. Hutchinson @Pixel2022





Track reconstruction

- Track reconstruction using Corryvreckan
- Use 3 telescope layers (L1, L2, L4) for track iterative alignment and L3 as DUT
- Preliminary results from one telescope using a long run at 6 GeV, bias at 50 V



Correlation of L2 with respect to L1 in X and Y

Map of associated clusters in DUT plane

Cluster size, charge, Residuals

- Dominated by single-pixel cluster expected given the pixel size
- Charge of clusters associated with tracks follow Landau distribution
- Peaks in residual distributions (defined as $x_{track} x_{hit}$ in DUT)
 - Due to large pixel size and single-pixel clusters in telescope planes



Sensor development

- ATLASPix was developed with TSI 180nm HV process, new sensor development for CEPC should be pursued
 - Smaller pitch, lower power consumption, lower noise ...
 - CEPCPix
 - Smaller pixel size in $r\phi$: 50 μ m \rightarrow 25 μ m
 - Low-power amplifiers and comparators
 - Daisy chain of readout reduces number of data links in case of low occupancy
 - Submitted in 2022 together with LHCb



Sensor development

- Attempts to explore alternative foundries
- HLMC 55nm HV CMOS process
 - Seeking MPW opportunity
 - Caveat: not supporting high-resistivity wafer
- SMIC 55nm CMOS processes
 - Possible to use high-resistance wafer
 - MPW submitted with Low-Leakage process in Oct 2022 with simple design of passive diodes and a few amplifiers
 - Seeking MPW opportunity using HV process and high resistance

	Internet Statements					The second state and second to				COLUMN A DATE OF THE
			100 C							
Concerning Street and	and the second sec	000	and the second s	and the second s	COLOR MANAGEMENT	illing and a second sec	Statement of the local division of the local	and the second division of the second divisio	000	100
	COLUMN DESIGNATION.	COLUMN TWO IS NOT THE OWNER.	Conceptuation of	COLUMN STREET, ST. OF	COLUMN AND ADDRESS OF	Concession and the	Concession and the second second	COLUMN AND DESCRIPTION OF	COLUMN DESCRIPTION OF TAXABLE PARTY.	and the second division of
		000 000 000 000		100 million 100					100 million 100	
		1111 - C	Sector Barrows	Concession of the local division of the loca	the second se	and the second s	States and States	the second se		Statement and Printers
and the second division of the second divisio	Statement and Advances of	1000	and the second s	and the second s	Concession of the local division of the loca		Concession of the local division of the loca	Concession in the local division of the loca	1000	Concession of the local division of the loca
		000		States and States	and the second s		Statement of the local division of the local	and the second diversity of		and the second second
Concession & Street, and	COLUMN STREET,	No. of Lot, House, Street, and Lot, or other	Concession and succession	COLUMN OF STREET, STREET, ST.	COLUMN TWO IS NOT THE OWNER.	the second se	Concernently and and a	And and the sure of	No. of Concession, name of Concession, or other	Concession of the local division of the loca
1000 miles 1	and the second division of the second divisio	0000-000-00	and the second s	and the second s	Colores and Colore	and the second s	Statement of Concession, Name	and the second s	1000 million and 1000	and the second second
	Concession of Streements			and the second s	No. of Concession, Name	the second se	Street and St	and the second division of the second divisio		
and the second division of the second divisio	the second second second	William seat and seat of the	Concession of the local division of the loca	Concernant of the second second	and the second s	and the second s	Name of Column states of	the same and it is not say it.	Statement of the local division of the local	100
and the second se	Statement of Concession, name		COLUMN STREET,	Statement of the local division of the local	Concession of the local division of the loca	Non-second survey of	COLUMN TWO IS NOT	Street and	No. of Concession, name	Statement of Street, or other
	Concession of the local division of the loca	1000	and the second s	and the second division of the second divisio	Statement in succession in the local division in the local divisio	and the second se	Concession of the local division of the	Concession in the summer of	and the second s	Contraction of the local division of the loc
		000 0	and the second s		and the second s		the second se	Statements in succession in which the succession in which the succession is not the succession in the		
Contract of the local division of the local	and the second division of the second divisio	000 0	and the second s	and the second s	CO. CO.	and the second s	the second division of	and the second division of the second divisio	100	100
A second s	Conceptual and	State and some of	the second second	the second se	and the second s	the second second	Concernance of the local division of the loc	the second second second	Statement over 1	and the second data
	and the second s	000	and the second s	and the second s	and the second division of the second divisio			and the second s	and the second s	
	Concernant of Co	000 0	100	Concernant of Co	and the second s	and the second s	Concession of the owner of the	Concession Names and Address of the Owner, or other	0.00	
1	and the second s		and the second se	-	-	the second se	Conceptual designation of the local division			Statement of the local division of the local
1000	1 P	000 0		1000 - 100 -	and the second s	and the second s		and the second s	0.00	100
and the second second	and the second second	Million and Marcol	No. of Concession, Name			and the second second	Street Barrier	and the second s	and the second s	and the second s
CONTRACTOR OF TAXABLE PARTY.	and the second se	0.0	(Comparison of the local division of the loc	and the second se	COLUMN TWO IS NOT	Contraction of the local division of the loc	the second s	Concession in the local division in the loca	100	the second second second
A new years and the second sec	Concernent Streements	1000	and the second division of the second divisio	and the second division of the second divisio	100 million (100 million)	and the second s	Comment of the local division of the	Comments and and	and the second s	
	Statement of Concession, Name	in the second se	and the second s	and the second se	Concession of the Owner, which the Owner			and the second division of the second divisio	and the second s	Concession of the local division of the loca
(()) () () () () () () () () () () () ()	and the second s	(000		and the second s	COLUMN TWO IS NOT	IIII IIIII	and the second se	and the second s	100	and the second second
and the second designed of the second designe	Contractor of Contractor	and the second data and the	and the second division of the second divisio	Colorado de Calendaria ((inclusion of the second se	and the second division of the second divisio	Concession of Concession, Name	() and the second second	and the second s	and the second s
	and the second se	100		and the second se	and the second se	and the second se	Concession of the local division of the			
and the second diversion of th	and the second s	and the second s	and the second s	and the second s	and the second s	the second second	Comment of the local division of the local d	the second second		
I I I I I I I I I I I I I I I I I I I	(Internet internet)	010	(Income Streems)	(IIII)	A CONTRACTOR OF THE OWNER OWNER OWNER OF THE OWNER OWN	Contraction of the local division of the loc	Concerning of Streeming of St	and the second s	III I COMPANY OF THE OWNER OF	Concerned the second
Concernant and some one	COLUMN IN COLUMN	little and the second	Concession of the local division of the loca	Colora of Streeman (Conception and Personnel Voter	And in case of the local division of the loc	Colorador and Co	Concerning Street, or other	and the second s	and the second data
1000	Contraction of the local division of the loc	000 0	100 million - 0	100 C	COLUMN TWO IS NOT	100-00-00-00-00-00-00-00-00-00-00-00-00-		Conception of the local division of the loca	100	100
and the second s	Concession in Fight services of			and the second s	No. of Concession, Name	the second se	Concession of the local division of the loca	Conception of the local division of the loca		
1001	and the second second	000 000 0	Concernance of the local division of the loc	and the second s	and the second division of the second divisio	and the second second	Statement of the local division of the	Concession of the local division of the loca	100	100
and the second division of the second divisio	COLUMN STREET, SQUARE,	and the second party of the second se	and the second s	COLUMN DESIGNATION OF	the second s	the second s	COLUMN TWO IS NOT THE	the second se	and the second s	Statement Street
	Statement of the local division of the local	000	and the second se	and the second s	COLUMN TWO IS NOT	100 million and 100 million	Statement of the owner where the	All and a local division of the local divisi	1000 - C	100
and the second division of the second divisio	Name and Address of the Owner, which the	and the second s	ilian and a summer of	the same of the same of the	Statements (Summerica)	Statement and the surgery of	Street or other Designation of the local division of the local div	Street St	and the second s	
and the second se	COLUMN AND INCOME.	and the second se	Stream and Streams	COLUMN AND DESCRIPTION OF	COLUMN TWO IS NOT	Concerning in such	COLUMN AND DESCRIPTION OF	COLUMN DESIGNATION OF TAXABLE PARTY.	and the second design of the s	Statement and Diversion
and the second division of the second divisio	Statement of Streeman (State of the second state	(Conceptor and	Statement and the summer of	Concernance of the local division of the loc	Concession of the local division of the loca	Column and Descent	Conception of the local division of the loca	State of the local division of the local div	Concernance in the local division in which the local division in t
	Concession of the International Property lies in th			and the second s	and the second division of the second divisio		Concession of the Assessment of the	the second division of	1000	
	(1)	000 000 000 000	100	100 C	100	100 million (1)		11	0.00	100
COLUMN DESIGN ADDRESS OF	COLUMN AND DESCRIPTION OF	The same part of the local division of the l	Conceptories and	Concession of Concession (Concerning in succession	the second second	Concept of the second of the	and the second division of the	Statement of the local division of the local	And in case of the local division of the loc
							ERFERIE			
2 2 2										
	00, 0000, 0000	2000, 2000, 200								

Test matrix for HLMC MPW (KIT)



Floorplan for SMIC LL MPW (IHEP, HNU, ZJU)

Sensor development

- Development of wafer scale CMOS pixel sensor (SDU, IHEP, HIT, DLMU)
- XFAB 350nm CIS process with stitching technique and highresistivity wafer
- First design submitted in Feb 2023
 - Wafer-scale sensor: ~ 11 × 11 cm²
 - Pixel matrix: 644 × 3600
 - 92 rows × 600 columns per reticle
 - Full function integrated:
 - Analogue pixel matrix
 - Column-level discriminator
 - On-chip zero-suppression
 - Other periphery blocks: Bias DAC/Buffers/I2C/PLL/LVDS/LDO...





Floorplan of the first wafer-scale sensor

From quad to stave demonstrator

- A stavelet demonstrator with 12 quad modules under development
 - Aggregation of data + optical conversion at end-of-stave; serial powering
 - Foreseen to be populated with ATLASPIX3



Mechanical design

- Design target: 0.65% X₀ for stave + modules
- CDR baseline design: 2 SIT layers



Simulation of truss rigidity

Thermal simulation for 2 vs. 4 cooling pipes

SET

|cosθ|=0.923

Outline

- CEPC Tracker Introduction
- R&D Status:
 - HVCMOS Sensor
 - ATLASPix3 results
 - QuadModule
 - stave demo
 - mechannical design
- Infrastructure, expertise
 - ATLAS ITk, AMS L0, LHCb UT

Silicon Tracker Production

• Constructed ISO Class 7 clean room, ~100m², at IHEP



Weiguo and Peilian's talks

ATLAS ITk Strip Module Production



• Metrology for position and tilt, and glue height



• Pull test to measure the strength of bonded wires







AMS L0 Silicon Tracker



13

Hesse BJ855 in Hall No.3

Yiming' s talk

LHCb Upstream Tracker

Chinese contribution



- Chinese groups play a key role
- Study of SEE effects in SALT chips using domestic and oversea facilities
 - CSNS, CIAE
- Integration and installation at CERN

Supported by NSFC project 11961141015 "LHCb升级中径迹探测器和数据获取系统的研究"





A-side installation complete



C-side installation complete







Summary

- CMOS-based silicon tracker is a promising solution for CEPC
- Development and prototyping have been progressing mostly using ATLASPix3 sensors
- R&D on HVCMOS pursued at various foundries
- Stavelet demonstrator and mechanical design in progress

Backup

Readout system

- GEneric Configuration and COntrol System
 - Versatile system for different applications designed at KIT
 - LFP-FMC connection to Nexys FPGA, PCIe x16 to DUT, allows extensive tests
 - Configurations: Single-board; Telescope; Quad



ATLASPix3 tests

- IV scan confirms sensor electrical characteristics: breakdown up to 60V
- The 3-bit TDAC in pixel allows tuning threshold for each pixel to gain homogenous response across sensor array (Trimming)
- ToT: a measure of deposited energy; calibration needed due to non-linearity



Noise ~60 e-For threshold ~1700 e-

Hitmap

• Both telescopes and the quad response to the beam



Event display of all layers