Measurements of SOI Detectors
INTPIX 3a, 3b and DIPIX CZ-n, FZ-n

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AGH-UST and IFJ-PAN Krakow
In collaboration with KEK Tsukuba (Japan)

Supervisor:

Prof. Marek Idzik (AGH)
Dr. Piotr Kapusta (IFJ)
Prof. Michal Turala (IFJ)

MC-PAD Closing Event, 19-22 September, 2012
Laboratori Nationali di Frascati, INFN

Akademia Górniczo-Hutnicza
im. Stanisława Staszica
w Krakowie
AGH

Instytut Fizyki Jądrowej
im. Henryka Niewodniczańskiego
Polskiej Akademii Nauk

About me

Home country : India

Past background:

- Finish Bachelors in September 2005, Osmania university India
- Graduated in July 2009, University of Luebeck, Germany.
- MC-PAD: P10 - Monolithic Detectors (Sep'2009-Aug'2012)

Present status:

- PhD student : AGH-UST (Possibly finish PhD thesis until sep'2013)
- Thesis advisor : Prof. Marek Idzik (AGH-UST) and Prof. Michal Turala (IFJ-PAN)
- No funding (Any suggestion, how to find funding?)

Outline

1. Motivation
2. SOI CMOS Technology
3. Test and Measurements
4. Achievements
5. General Aspects

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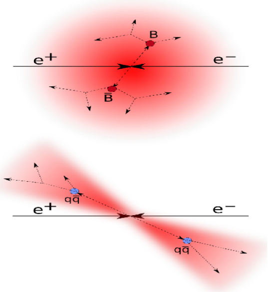
Motivation (Physics)

- In Particle Physics silicon detectors, strips and pixels, are used to detect trajectory of particles with high precision:
  - To help in track reconstruction to identify primary vertices (at LHC, in pp collisions, there are up to 20-30 simultaneous interactions, each with many tracks; in Pb-Pb collisions thousands of particles are produced)
  - To increase the precision of momenta measurements
  - To allow for identification of secondary vertices of short living particles and measuring their lifetime (B-physics experiments)
- Tracking detectors located near-by the collision point have to have following features:
  - High granularity (Events at Belle II, LHC and other HEP experiments result in huge number of ionizing particles passing through the detectors)
  - Mass as low as possible (as it is responsible for multiple scattering of particles and conversion of photons which changes the original pattern of primary interactions)
  - High precision of position measurements with truly 2-D readout (if possible), to avoid combinatoric problems in reconstruction
  - Be radiation resistant

Examples

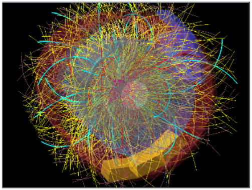


Case of B-factories

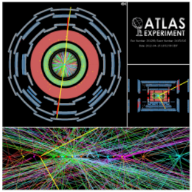
The lifetime of B mesons is only a fraction of the ps….

Their decay paths are in order of few mm (even with substantial Lorenz boost…).

LHC case



Event displays from lead ion collisions recorded by ALICE (6.11.2011)



An ATLAS event with more then 20 reconstructed vertices (20 overlaid minimum bias events)

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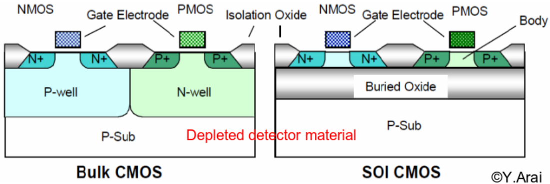
Bulk CMOS vs SOI CMOS

Comparison of Bulk and SOI CMOS



Features of SOI CMOS technology :

- Latchup free - No parasitic PNPN structure
- High Temperature operation - No latchup, less leakage, less Vth Shift
- Low junction capacitance - High speed and Low Power
- Small area - No well isolation
- Good Radiation hardness and
- Low cost

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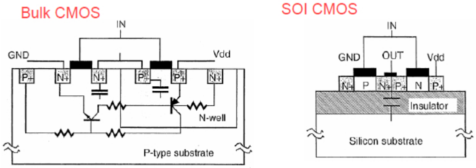

(Ref. 'SOI Technology' by Jean-Pierre Colinge, Springer)

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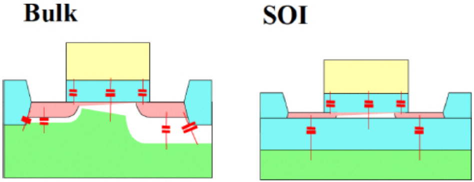

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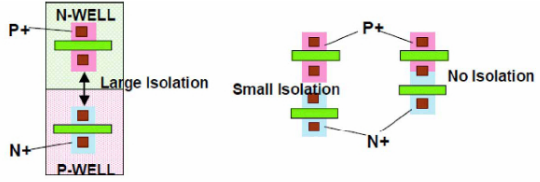

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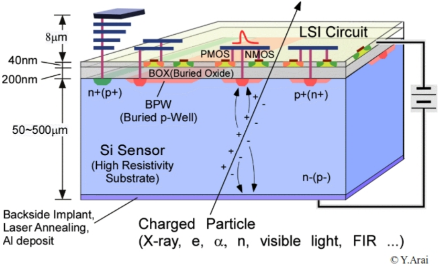
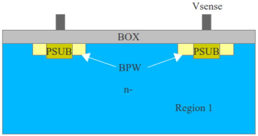
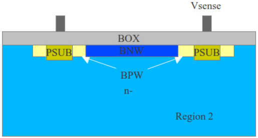
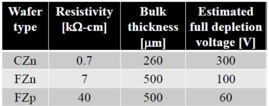
SOI CMOS Pixel



Process	0.2μm low leakage fully depleted SOI CMOS 1 poly + 5 metal layers, MIM(1.5μF/μm^2), DMOS Core(I/o) voltage=1.8(3.3)V, Buried p/n Well
SOI wafer	diameter: 300 mmϕ Top Si: Cz$\sim$18Ωcm(p-type), 40nm thick Buried oxide: 200nm thick Wafer: Cz(n, 0.7kΩcm), FZ(n, 7k), FZ(p, 40k)
Backside thickness	Cz: thinned to 260μm, sputtered with Al(200nm) Fz: thinned to 500μm (no Al) Devices thinned to (50,100μm) available



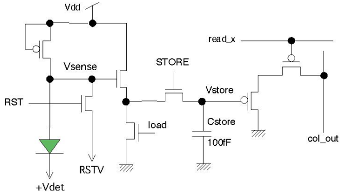




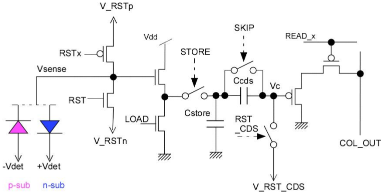
Wafer type	Resistivity [kΩ-cm]	Bulk thickness [µm]	Estimated full depletion voltage [V]
CZn	0.7	260	300
FZn	7	500	100
FZp	40	500	60

INTPIX3 and DIPIX2

- INTPIX is signal integration type pixel detector
- Two detectors are tested in the family of INTPIX3 (INTPIX3a, INTPIX3b)



- DIPIX is dual mode integration type pixel detector
- Two detectors are tested in the family of DIPIX2 (CZ-n, FZ-n)



	pixel size [μm]	No. of pixels	Effective area [mm]	chip area [mm]	Fabrication year	No. of pixel type	CDS in pixel
INTPIX3a	20 × 20	128 × 128	2.56 × 2.56	5 × 5	FY08	8	No
INTPIX3b	20 × 20	128 × 128	2.56 × 2.56	5 × 5	FY09-1	8	No
DIPIX2	14 × 14	256 × 256	3.584 × 3.584	5 × 5	FY10-1	2	Yes

Outline

Study of pixel behaviour

Long time stability test

Stability test is to check whether the detector is capable of operating in long run measurements.

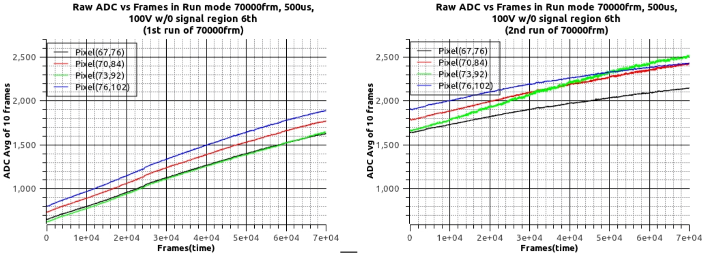
Test Setup :

Parameters	**INTPIX3**	**DIPIX2**
Environment	Dark	Dark
Signal	No	No
No. of Frames	70000	40000
Integration Time	500μs	500μs
Scan Time (pixel readout time)	1000 $ns/pixel$	640 $ns/pixel$
RST time without cds and with cds	1000ns and -	2040 ns and 2160 ns
RSTV for N and P-type wafer	700mV	750mV and 1300mV

- The Back voltage for both detector = 100 V.

Results of Stability test (INTPIX 3a and DIPIX2 CZ-n)

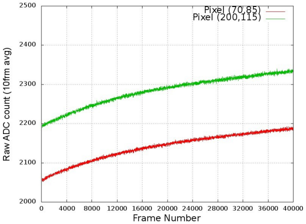
INTPIX 3a



Raw ADC vs Frames in Run mode 70000frm, 500us, 100V w/0 signal region 6th (1st run of 70000frm)

Raw ADC vs Frames in Run mode 70000frm, 500us, 100V w/0 signal region 6th (2nd run of 70000frm)

DIPIX2 CZ-n



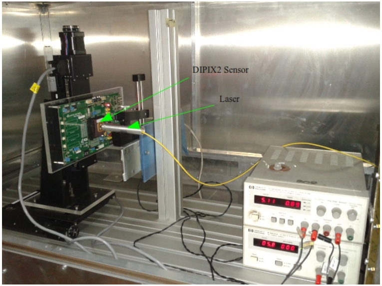
Summary

- DIPIX2 is stable contrary to INTPIX3 and so it may work for long time run.
- Small initial changes in number of counts in DIPIX2 may probably be reduced by maintaining a constant temperature.

see backup slide for more detail

Laser parameter and setup

Laser Details	
Laser Driver	PDL 800-D
Frequency	80 MHz
Modes of operation	Pulse
Laser Head wavelength	1060 nm
3D motorized stage	X,Y and Z



- The laser with 1060nm of wavelength is used and placed at a distance of 0.7mm from the detector.
- The smallest spot size can be achieve from this laser is about 8 μm and the pixel size is 20μm.

Results of Laser (INTPIX 3a)

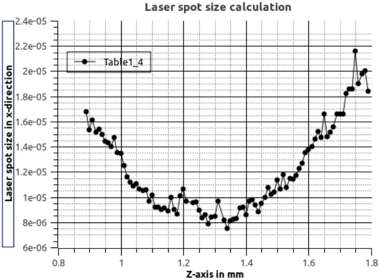


Figure: X-direction

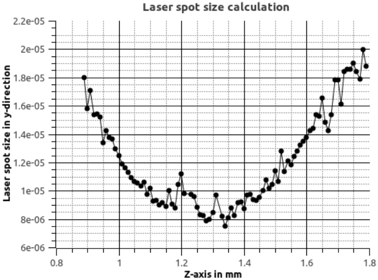
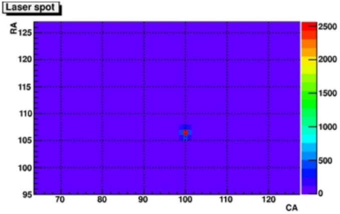


Figure: Y-direction



Results of Laser (DIPIX FZ-n)

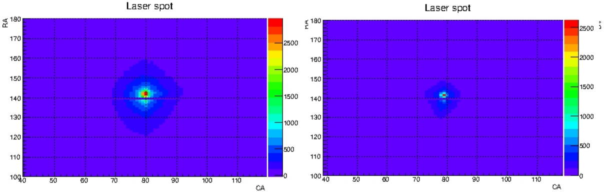


Figure: Back voltage was set to a) Left fig. 10V, b) Right fig. 70V (FZ-n)

- A bunch of pixels around the hit pixel(halo) having 12 to 15 % of hit pixel count is seen.
- This problem is seen in both sensors. The worse is FZ-n.
- Halo depends mostly on Laser Intensity (increase with intensity).

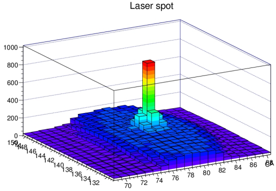
Results of Laser (DIPIX FZ-n)

Optimized Back Voltage and Integration Time

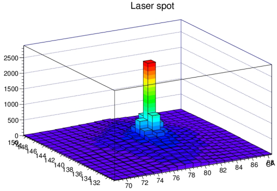
Parameters	CZ-n Type	FZ-n Type
Back Voltage	80V	60V
Integration Time	100μs	100μs

- The presence of Halo, force us to do the scan of back voltage and Integration time to optimize them in order to reduce halo.
- Optimization is used to reduce the Halo and spot size.

Before optimization



After optimization

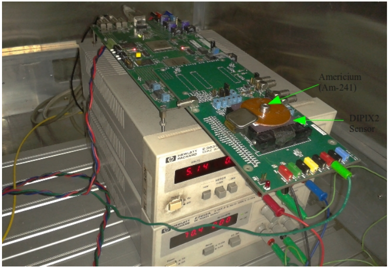


Americium radiation data and setup

- Am-241 source is used with the activity of 10mCi(=370MBq).
- The rate of incident photons is low.
- Setup is placed in black box.

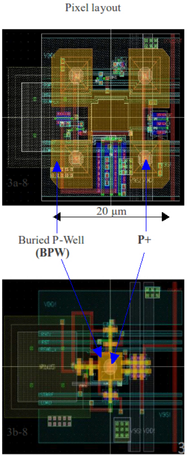
Radiation Data	
Type	Energy
Gamma	59.5KeV 26.3KeV 13.9KeV
Cu L x-ray	8.01KeV
Np L-x-ray	17.7KeV
Np L-x-ray	20.7KeV

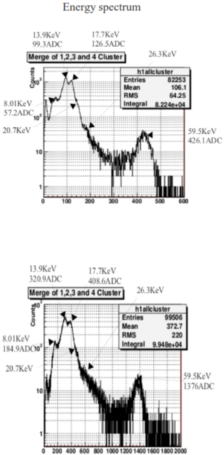
Detector	Parameter setting (Am-241)	Parameter setting (Pedestal)
INTPIX 3a	I.T = 100 μs RSTV = 750mV Events = 25000	Scan Time = 1000ns/pixel Reset length = 240ns Frequency = 95Hz Events = 500
INTPIX 3b	I.T = 250 μs RSTV = 550mV Events = 10000	
DIPIX 2	I.T = 100 μs RSTV = 750mV Events = 20000	Scan Time = 640ns/pixel Reset length = 2040ns Frequency = 22Hz Events = 500



- Bias voltage = 100V and black box is use for the measurement.
- Pedestal data is used to remove bad pixels.
- Bad frames and common mode noise are removed from both pedestal and Am-241 run.

Results of Am-241 (INTPIX 3a and 3b)

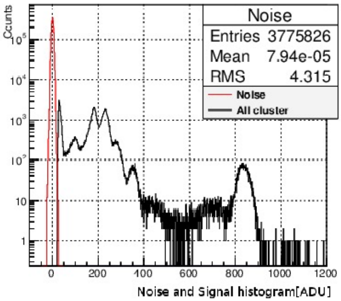

Pixel layout


Energy spectrum

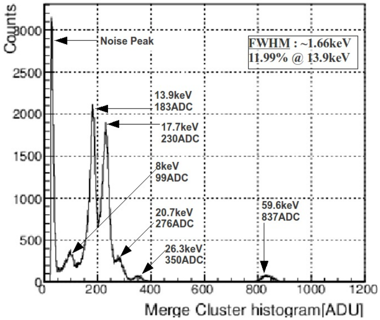
INTPIX 3A				
IT(μs)	Noise(ADC)	ENC(e^-)	SNR	Mean of 59.5KeV(ADC)
100	3.65	140	111.45	426.1
INTPIX 3B				
250	12.80	148.5	109.70	1409

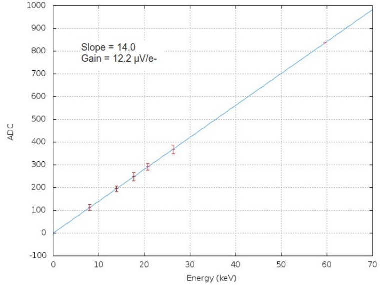
- Higher sensor gain with smaller BPW size

Logarithmic scale



Linear scale





ENC and SNR (DIPIX CZ-n and FZ-n)

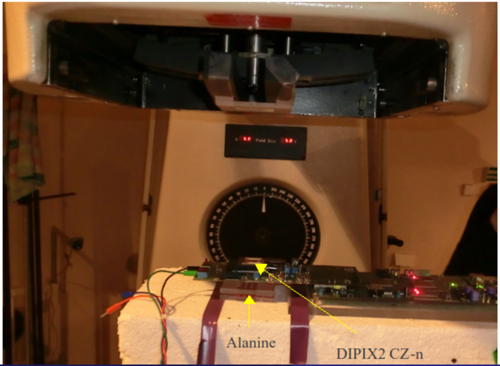
<table>
<tr><th colspan="6">CZ N-Type Without CDS</th></tr>
<tr><td>Region</td><td>IT(μs)</td><td>Noise (ADC)</td><td>ENC(e^-)</td><td>SNR</td><td>59.5KeV (ADC)</td></tr>
<tr><td>1</td><td>100</td><td>4.3</td><td>$\simeq$86</td><td>$\simeq$189</td><td>812</td></tr>
<tr><th colspan="6">CZ N-Type With CDS</th></tr>
<tr><td>Region</td><td>IT</td><td>Noise</td><td>ENC(e^-)</td><td>SNR</td><td>59.5KeV (ADC)</td></tr>
<tr><td>1</td><td>100</td><td>3.6</td><td>$\simeq$85</td><td>$\simeq$192</td><td>690</td></tr>
</table>

<table>
<tr><th colspan="6">FZ N-Type Without CDS</th></tr>
<tr><td>Region</td><td>IT(μs)</td><td>Noise (ADC)</td><td>ENC(e^-)</td><td>SNR</td><td>59.5KeV (ADC)</td></tr>
<tr><td>1</td><td>100</td><td>5.1</td><td>$\simeq$127</td><td>$\simeq$129</td><td>657</td></tr>
<tr><td>2</td><td>100</td><td>4.7</td><td>$\simeq$141</td><td>$\simeq$115</td><td>543</td></tr>
</table>

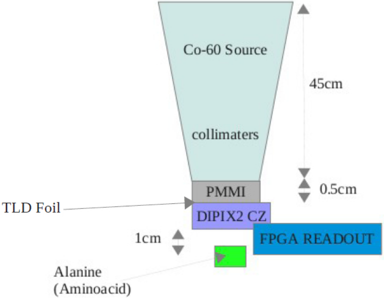
- 1st region is the best of both sensor (ENC=85e^- and SNR=189 using Am-241 source 59.6keV), 2nd region is having lot of bad and hot pixels.
- Readout with CDS give similar results.

Irradiation using Co-60 source

- DIPIX2 was irradiated with Co-60 γ's, and Dose rate was 1.43Gy/min.
- The irradiation was interrupted every 20 min (safety) and last for 12 hour in total.
- Before and after irradiation a TLD foil is used to know the beam profile.
- Alanine capsules (change every 40 min) are place below the DIPIX2 to calculate the dose rate.

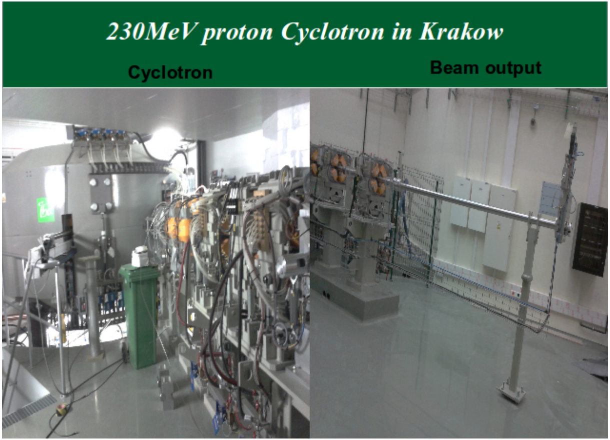


Setup using Co-60 source



Future plans

- Irradiate Double SOI and DIPIX2 detectors using CCB facility in Krakow.
- Measurements of new SOI detector (Designed at Krakow)
- TCAD simulation



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Publications

Publications

- **High-Resolution Monolithic Pixel Detectors in SOI Technology**
  International Workshop (PIXEL2012) on Semiconductor Pixel Detectors for Particles and Imaging (2-7 September 2012).
  Authors: Toshinobu Miyoshi, Yasuo Arai, Mohammed Imran Ahmed, Ryo Ichimiya, Yukiko Ikemoto, Ayaki Takeda, Piotr Kapusta, Yowichi Fujita , Kazuya Tauchi, (Paper under preparation NIMA)
- **Measurement Results of DIPIX Pixel Sensor Developed in SOI Technology**
  12th Pisa Meeting on Advanced Detectors, La Biodola, Isola d'Elba, Italy (20-26 May 2012).
  Authors: Mohammed Imran Ahmed, Yasuo Arai, Marek Idzik, Piotr Kapusta, Toshinobu Miyoshi, Michal Turala (Paper in print NIMA).
- **P-in-n and n-in-p sensor performance study of SOI monolithic pixel detectors**
  8th International "Hiroshima" Symposium on the Development and Application of semiconductor Tracking Detectors, Taipei, Taiwan 5-8 December 2011).
  Authors: Toshinobu Miyoshi, Yasuo Arai, Mohammed Imran Ahmed, Ryo Ichimiya, Yukiko Ikemoto, Ayaki Takeda (Paper in print NIMA)

Presentations and Reports

Presentations

- **Testing of SOI Pixel Detectors for Particle Physics**, 2nd CCB Users Meeting on Physics with the new 230 MeV proton cyclotron in Krakow (3rd September 2012).
- **Measurement Results of DIPIX Pixel Sensor Developed in SOI Technology** 12th Pisa Meeting on Advanced Detectors, La Biodola, Isola d'Elba, Italy (25th May 2012).
- **Measurements of DIPIX2 Sensors CZ-n, FZ-n and FZ-p** SOI Collaboration Meeting LBNL (16th March 2012)
- **Talk on INTPIX3 back-gate effect test results** FNAL SOI Collaboration Meeting (5th March 2010)

Reports

- Performance of INTPIX 3a and 3b
- Report on DIPIX Cz-n and Fz-n

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Overview of training programs and travels

MC-PAD Training

Course	Host institute	Dates	Related to my research
Readout Electronics	AGH-UST Krakow Poland	17-19 September 2009	Useful
Geant4 Simulation and ROOT analysis	DESY Hamburg Germany	28-30 January 2010	Useful
Radiation Hardness and Silicon processing	JSI Ljubljana Slovenia	26-30 September 2010	Useful
Gaseous and photo detectors	CERN Geneva Switzerland	16-18 March 2011	Useful
CV writing and interview skills	PSI Zurich Switzerland	8-10 November 2011	-
Heavy Ions and Calorimetry in HEP	GSI Darmstadt Germany	18-21 March 2012	-

Other Training

- Attend IDESA course on Digital design at Seville, Spain.
- TCAD simulation at KEK Tsukuba, Japan.

Acknowledgements

A big thanks to :

- Late Dr. Henryk Palka
- Marek Idzik, Michal Turala
- MC-PAD
- Christan Joram
- MC-PAD training event organizers

Negative aspects

- No participation from industry partners
- MC-PAD fellowship duration for ESR?

Thanks for your attention

Any question?

Backup:Stability Test of CZ-n pixel sensor

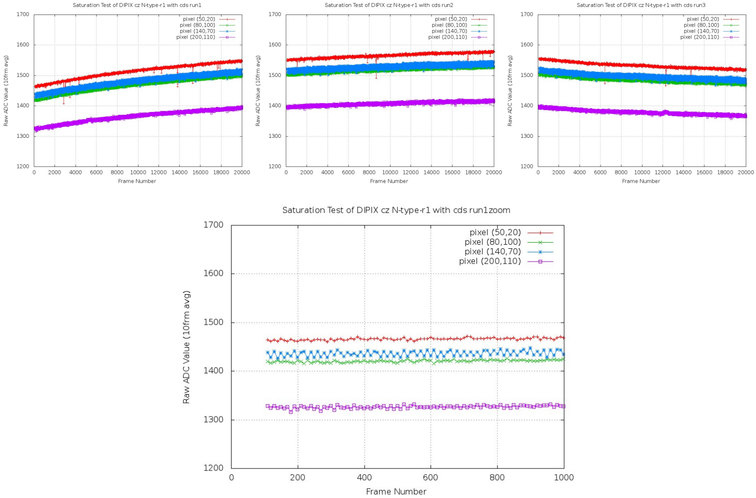

Figure: Stability test of CZ-n with CDS. (top 3 graphs each with 20000 frames measured subsequently and bottom is zoom of initial 1000 frames)