RD39 Status Report 2014-2015

Jaakko Härkönen and Zheng Li

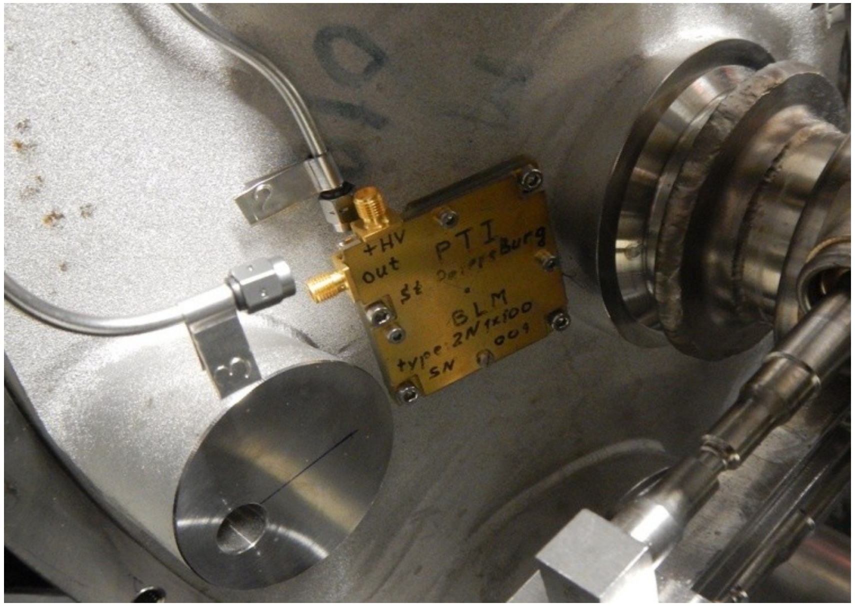
http://rd39.web.cern.ch/RD39/

Outline

- Motivation and background
- Status of Cryogenic Beam Loss Monitoring

 (BLM) project
- CLAP - A Compact Large Area Particle Detector
  - Why it’s needed in antihydrogen experiments ?
  - Challenges in making of thick Si detectors
  - Challenge in cryogenic operation
  - Workplan

- Summary

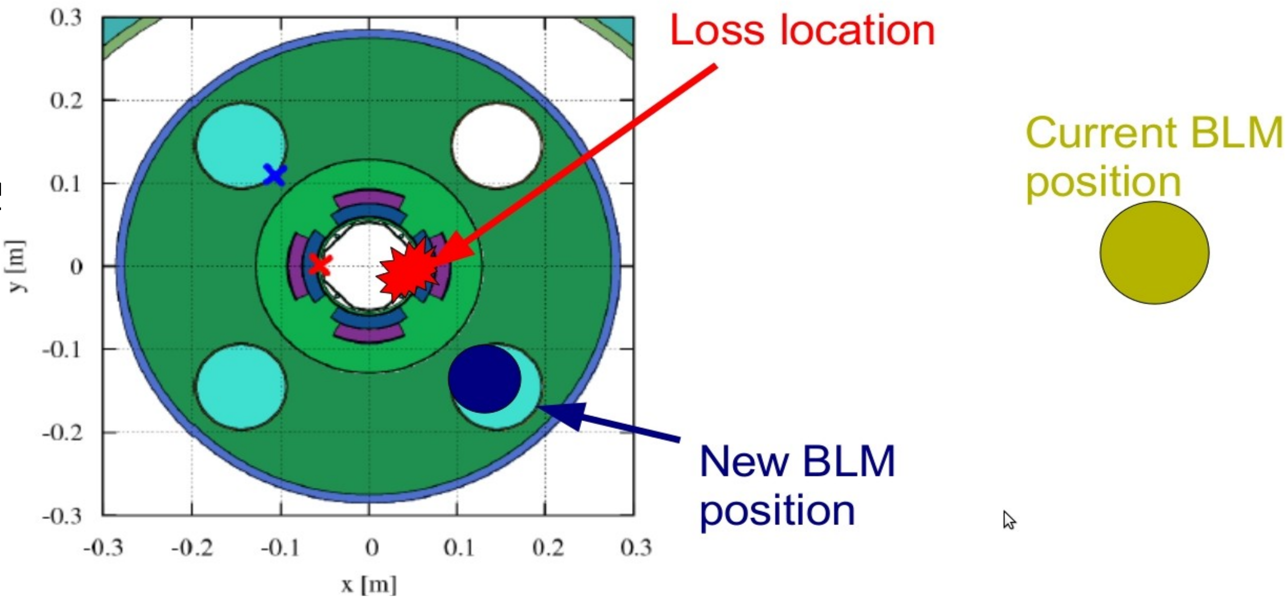


Motivation and background

•Beam Loss Monitors allow to **avoid magnet quenches** due to beam losses

•Current Beam Loss Monitors are gas ionization chambers installed **outside of the magnet cryostat**

•In some cases the large amount of material between beam loss location and the detector and presence of another radiation source leads to **masking of the signal at quench**.

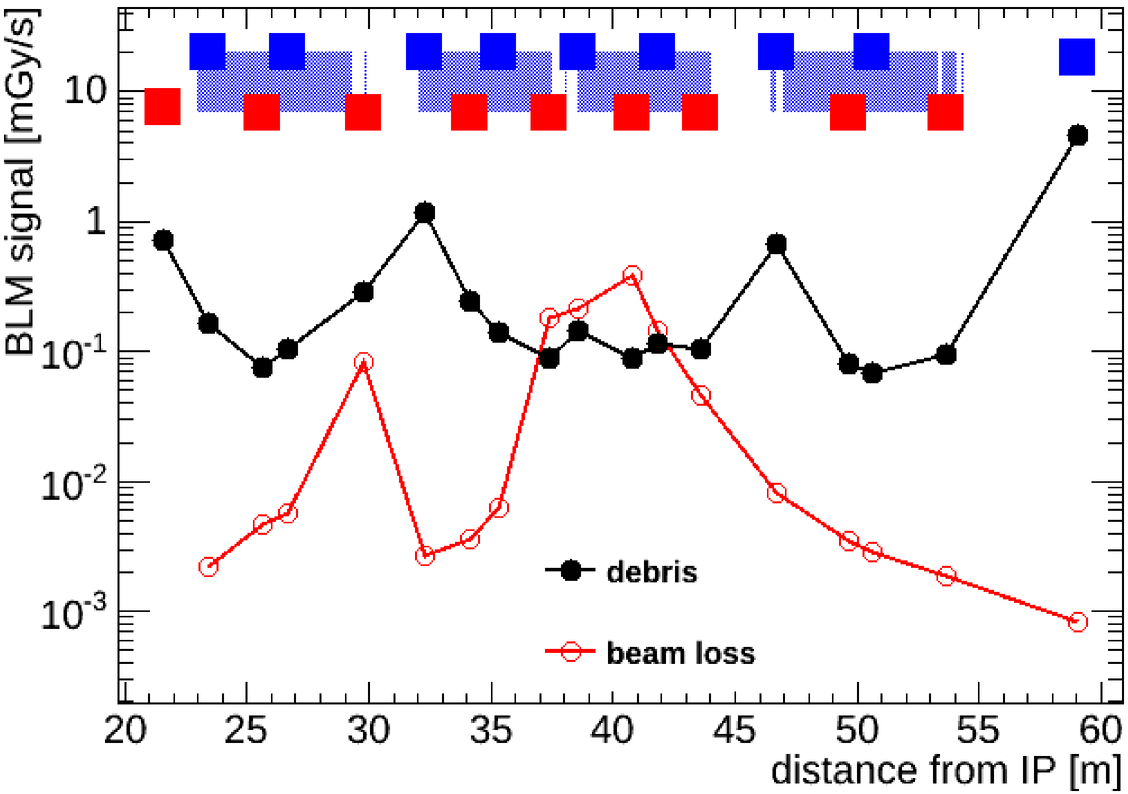


Motivation and background II

- Energy deposition from beam debris and/or beam loss might heat up LHe

- Fast pressure increase from 1.1 bar up to about 20 bar is possible resulting in irreversible damage to LHC

- Especially when the distance from IP is less than 30m, induces larger debris signal into BLMs than the beam loss

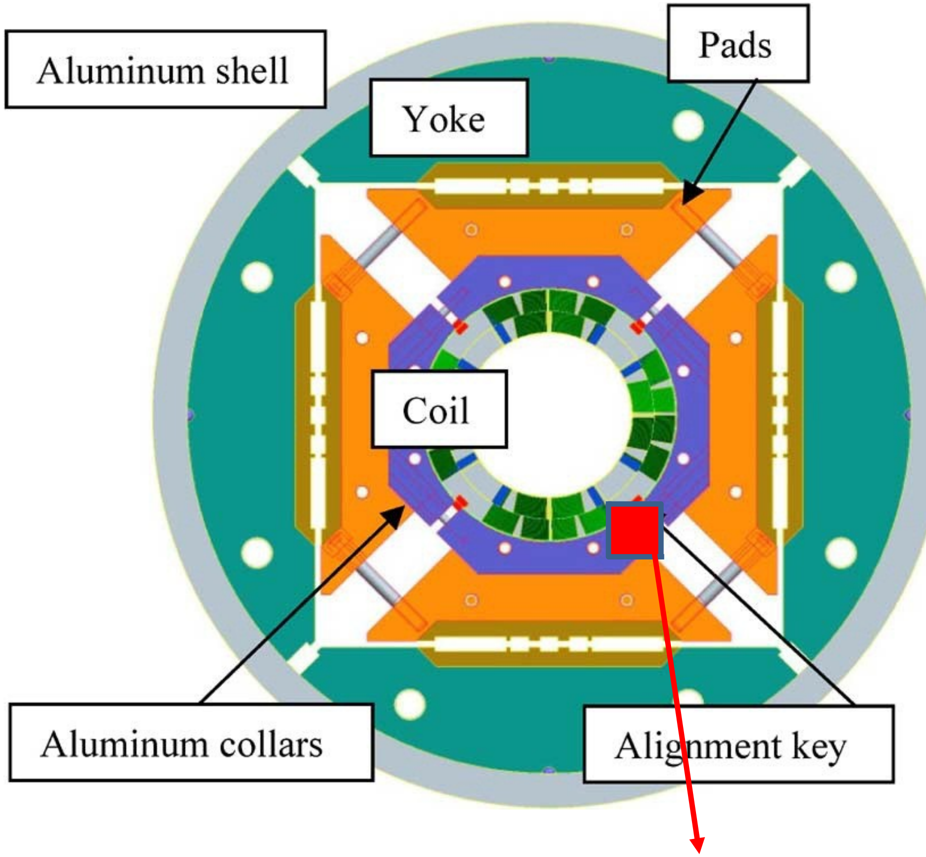


- Challenge: Si detector should operate at LHe temperature <2K and should simultaneously be radiation hard up to 1 MGy.
- At LHe temperature there is no annealing of radiation defects + shallow donor/acceptor impurities are not ionized
- Polarization effect may take place at very low temperatures

Requirements of beam loss measurement in upgraded LHC

- Solution: Installation of radiation **detectors inside magnet** as close to the coils as possible
- Environment: **T=<2K**,
- **dose 2 MGy** in 20 years,
- B-field = 4 T,
- pressure up to 20 bar, time response <1 ms
- Various technologies investigated: **silicon and diamond** detectors and LHe ionization chamber chosen for further tests.

MQXF cold mass



Location of Cryogenic BLMs

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In situ radiation test of silicon and diamond detectors operating in superfluid helium and developed for beam loss monitoring

C. Kurfürst [a], B. Dehning [a], M. Sapinski [a], M.R. Bartosik [a], T. Eisel [a], C. Fabjan [a], C.A. Rementeria [a], E. Griesmayer [b], V. Eremin [c], E. Verbitskaya [c,*], A. Zabrodskii [c], N. Fadeeva [c], Y. Tuboltsev [c], I. Eremin [c], N. Egorov [d], J. Härkönen [e], P. Luukka [e], E. Tuominen [e]

[a] *CERN, Geneva, Switzerland*
[b] *CIVIDEC Instrumentation, GmbH, Vienna, Austria*
[c] *Ioffe Institute, St. Petersburg, Russian Federation*
[d] *Research Institute of Material Science and Technology, Zelenograd, Moscow, Russian Federation*
[e] *Helsinki Institute of Physics, Helsinki, Finland*

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A B S T R A C T

As a result of the foreseen increase in the luminosity of the Large Hadron Collider, the discrimination between the collision products and possible magnet quench-provoking beam losses of the primary proton beams is becoming more critical for safe accelerator operation. We report the results of ongoing research efforts targeting the upgrading of the monitoring system by exploiting Beam Loss Monitor detectors based on semiconductors located as close as possible to the superconducting coils of the triplet magnets. In practice, this means that the detectors will have to be immersed in superfluid helium inside the cold mass and operate at 1.9 K. Additionally, the monitoring system is expected to survive 20 years of LHC operation, resulting in an estimated radiation fluence of 1×10^{16} proton/cm^2, which corresponds to a dose of about 2 MGy. In this study, we monitored the signal degradation during the *in situ* irradiation when silicon and single-crystal diamond detectors were situated in the liquid/superfluid helium and the dependences of the collected charge on fluence and bias voltage were obtained. It is shown that diamond and silicon detectors can operate at 1.9 K after 1×10^{16} p/cm^2 irradiation required for application as BLMs, while the rate of the signal degradation was larger in silicon detectors than in the diamond ones. For Si detectors this rate was controlled mainly by the operational mode, being larger at forward bias voltage.

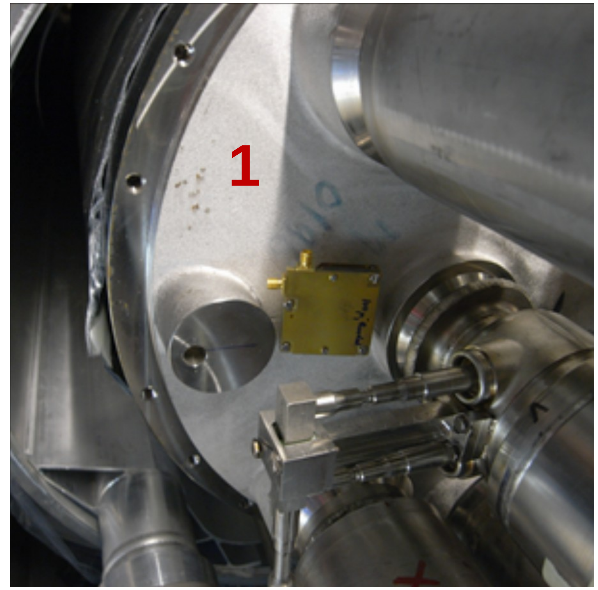
Status of semiconductor BLM development

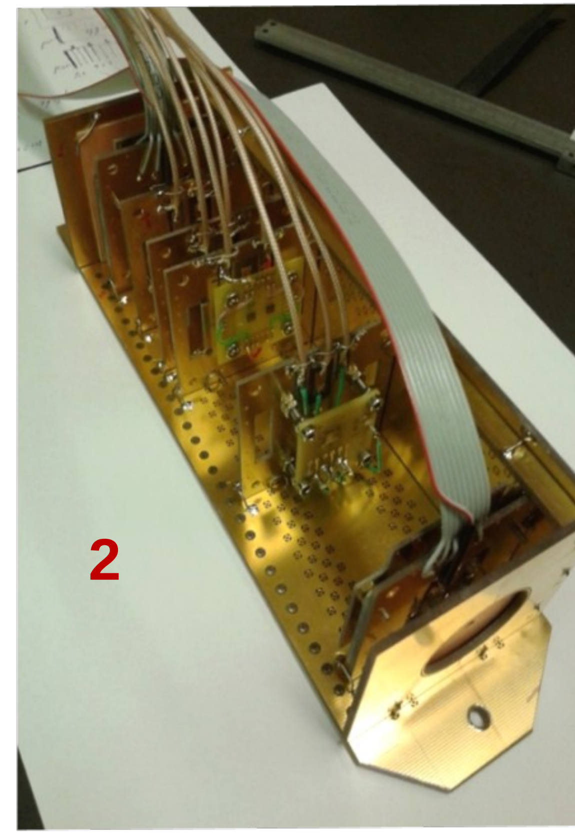
<u>April 2014</u>:
Si detector modules are installed on the magnets (**1**)

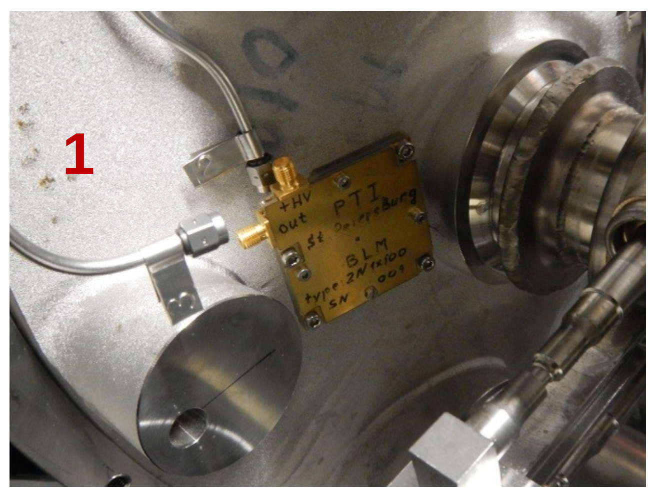
<u>December 2014</u>:
test of a new setup:
- new beam area,
- new cryostat,
- new acquisition system;
- **new detector module** (**2**)

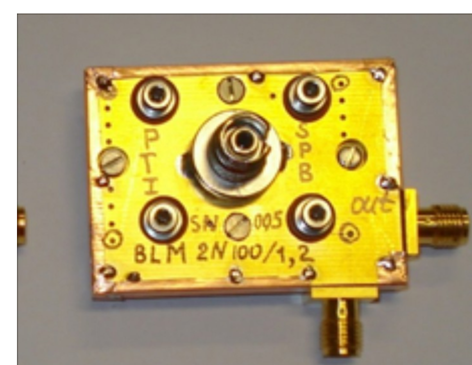
with Si detectors: Si pad, 300 and 100 μm, Si 3D, and diamond 3D

<u>2015 (plan)</u>:
New irradiation test



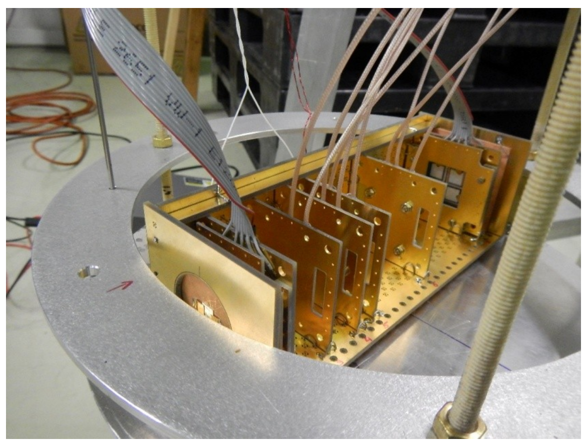




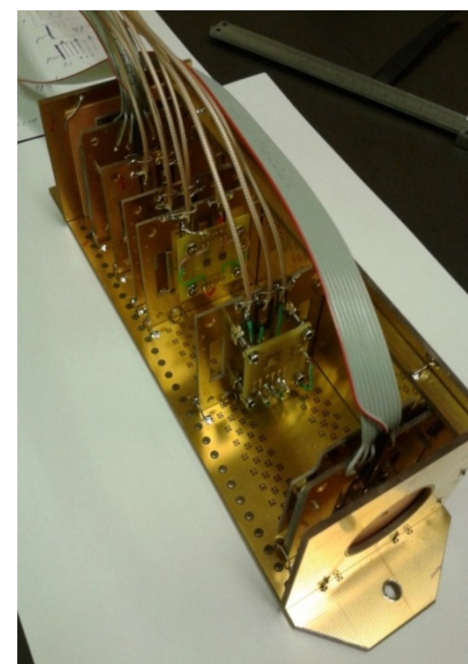


Test beam experiment 2014

Performed at IRRAD facility in PS East Area Dec 5-15, 2014: **new beam area**
Goal : upgrade and test of the units/items involved in the in-situ radiation test of CryoBLM
new cryostat,
new acquisition system which will be used for BLMs at LHC;



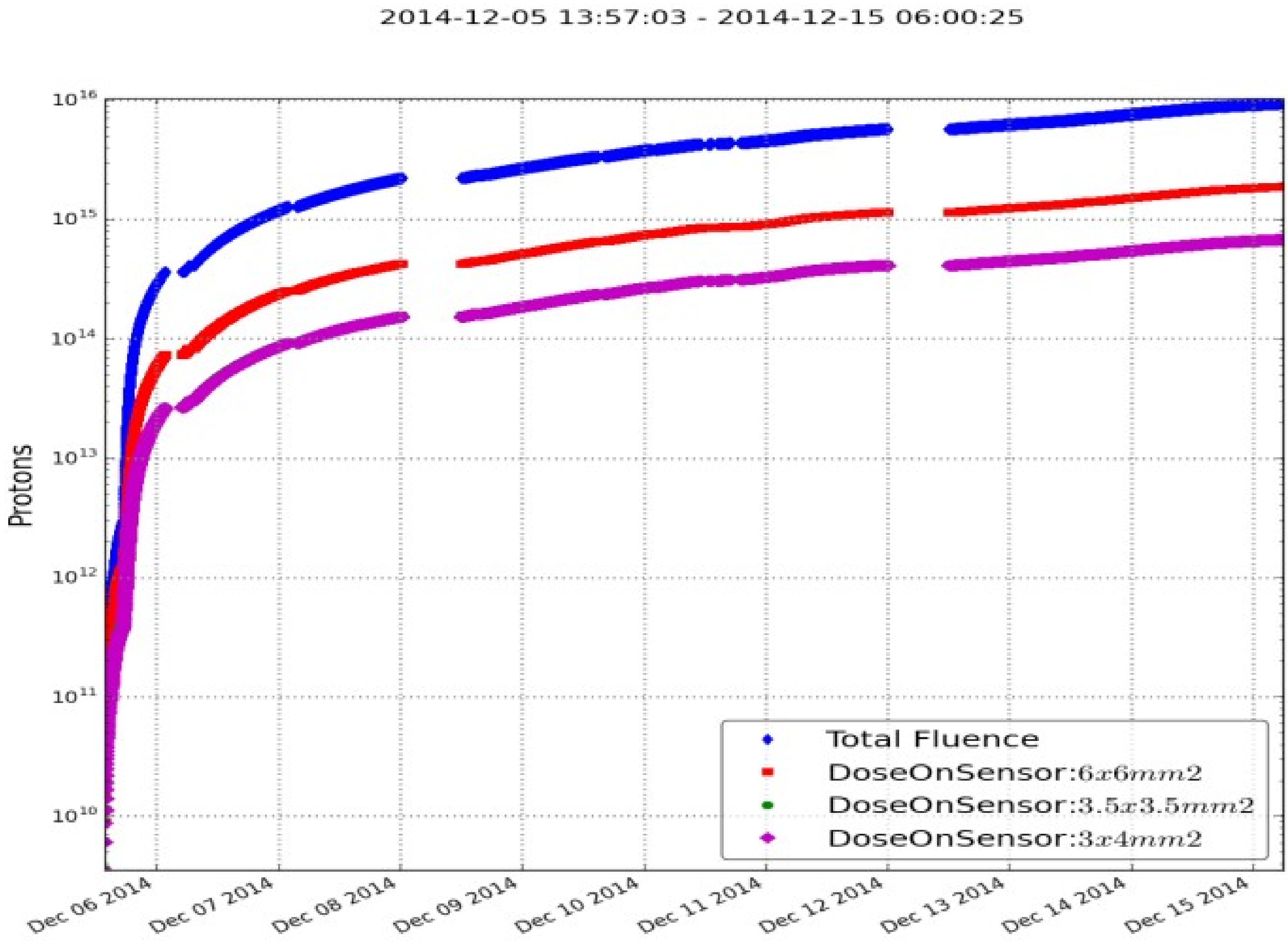
The test was performed between 05/12 and 15/12 at the IRRAD facility in PS East Area. A plan of the facility is depicted in figure 1.
The detectors used were two Silicon pad diodes of $100\mu m$ and $300\mu m$ and $6x6mm^2$ area, a 3D Silicon of $300\mu m$ and active area of $3.5x3.5mm^2$ and a 3D single crystal diamond sensor of $500\mu m$ thickness and active area of $3x4mm^2$. The two Si pad detectors were biased at $-100V$, the sCVD at $-100V$ or $100V$ and the 3D Si at $-5V$. The cassette with the aforementioned detectors as well as two telescope detectors at each end can be seen in figure 2.



Samples and conditions

The maximal accumulated fluence --- or 27000 spills

Device	Material	Thickness	Area	#	Voltage
Beam Telescope	Silicon	300μm	1.5 cm^2 4 chips	2	100
SI-pad1	Si	300μm	6x6 mm^2	1	100
SI-pad2	Si	100μm	6x6 mm^2	1	100
3D-SI	Si	300μm	3.5x3.5mm^2	1	5
3D-CVDD	Diamond	500μm	3x4mm^2	1	100

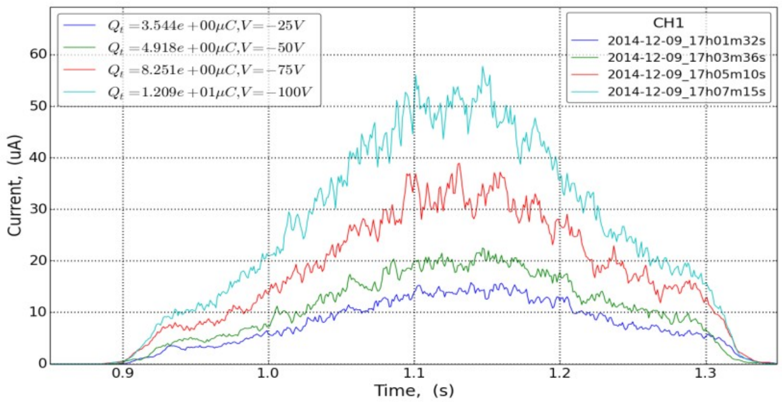


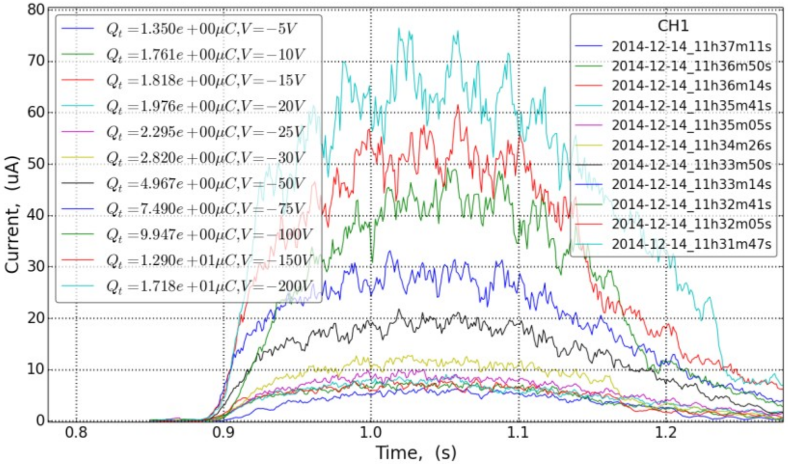
Maximal dose on SI pad – 2e15 cm^{-2}

Spill time-profile measured by SI-pads at the beginning of irradiation session and at the end

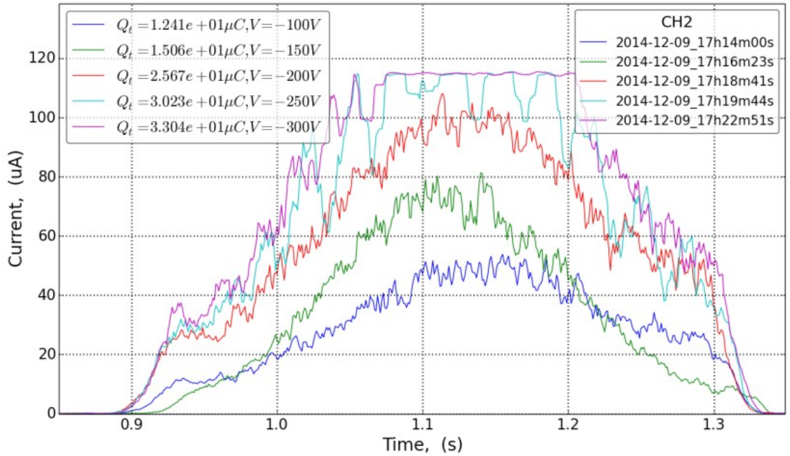
(100 um)

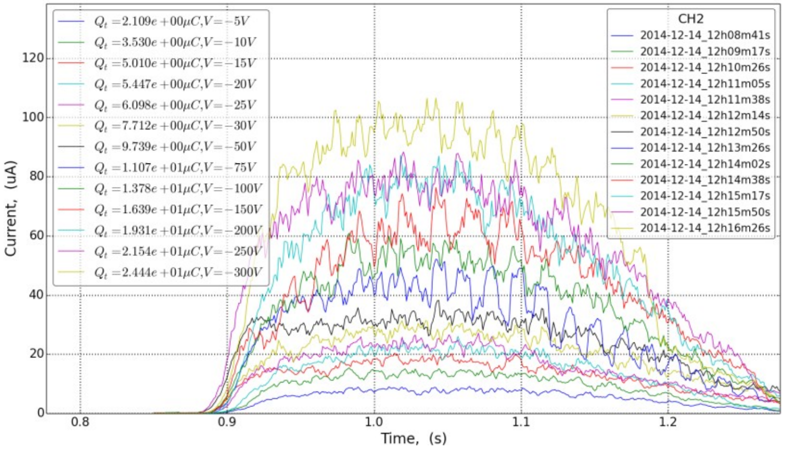
1e15 cm^{-2} (9/12, 2014) **2e15 cm^{-2} (14/12, 2014)**





(300 um)

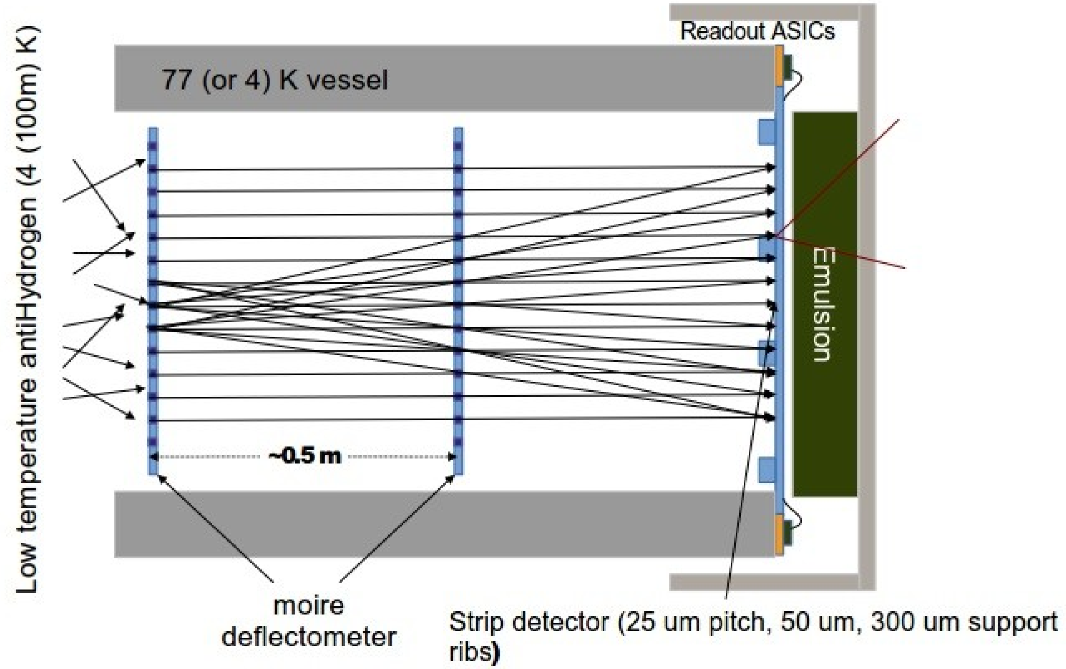


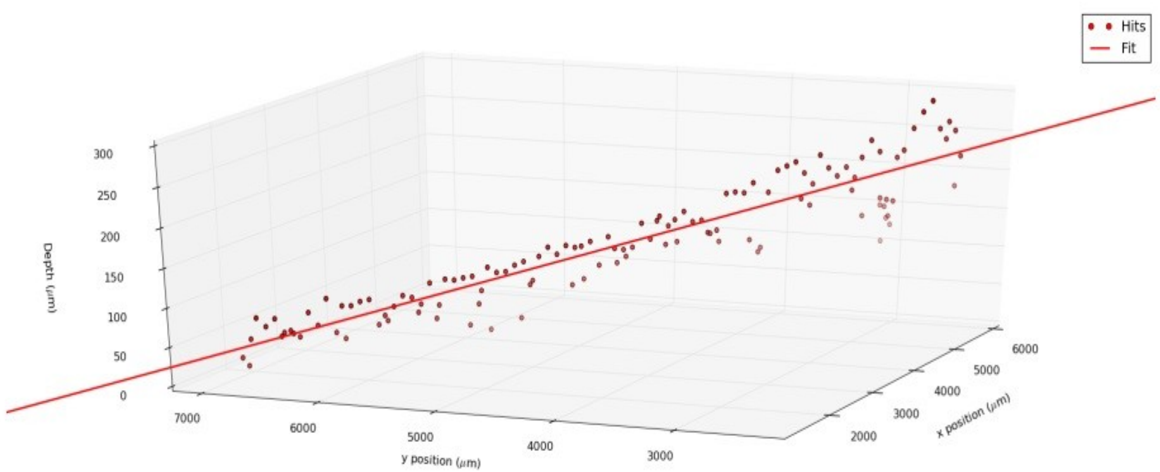


The beam time-profile was different on 9/12 and 14/12, 2014 that was detcted by SI-pads
The fluctuations on the pulses are fluctuations of the beam intensity (or position) of the beam (bunches structure)

CLAP - A Compact Large Area Particle detector

- Antihydrogen is detected through the observation of the charged products of a proton-antiproton
- Observation of at least two of the tracks associated to these products allows the reverse calculation of the annihilation
- AEgIS experiment has spatial constraints, but requires timing information in tracking.
- Emulsion foil is off-line detector → need for thick Si detector providing 3D tracks.
- Thick pixel detector attached to appropriate ROC ASIC must be operational at **cryogenic** temperature.





Challenge associated with very thick Si detectors

$$V_{fd} = \frac{d^2}{2\,\varepsilon_0\,\varepsilon_{Si}\,e\,\mu\,\rho}$$

• With usual thickness (e.g. 300µm) and usual Si resistivity (3-5k Ωcm), V_{fd} would be 50-100V.

• With desired thickness 2mm, the same resistivity would result in $V_{fd} \approx 4000$V.

• Thick Si sensors must be made of intrinsic (i.e. non-doped) silicon.

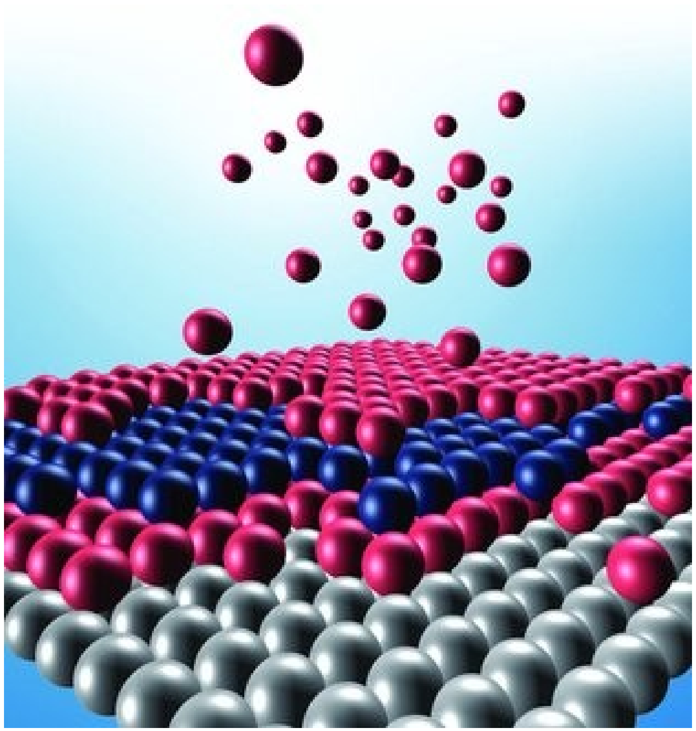
• Fz-Si with resistivity ~80k Ωcm is commercially available.

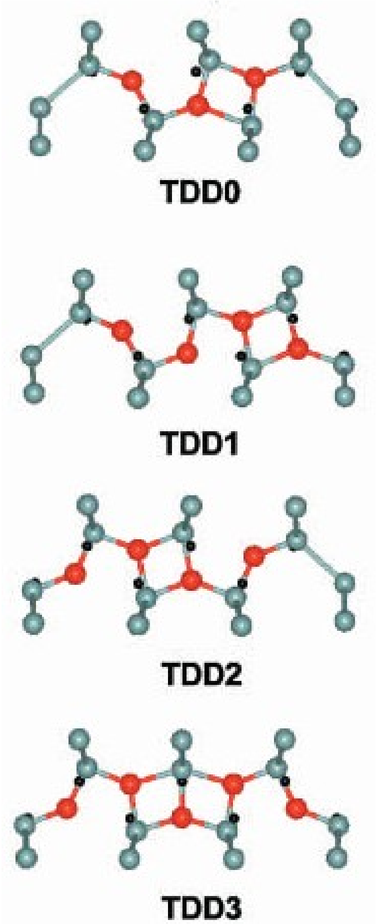
• Normal detector processing contains several thermal oxidations of Si wafers at ≈ 1100°C temperature.

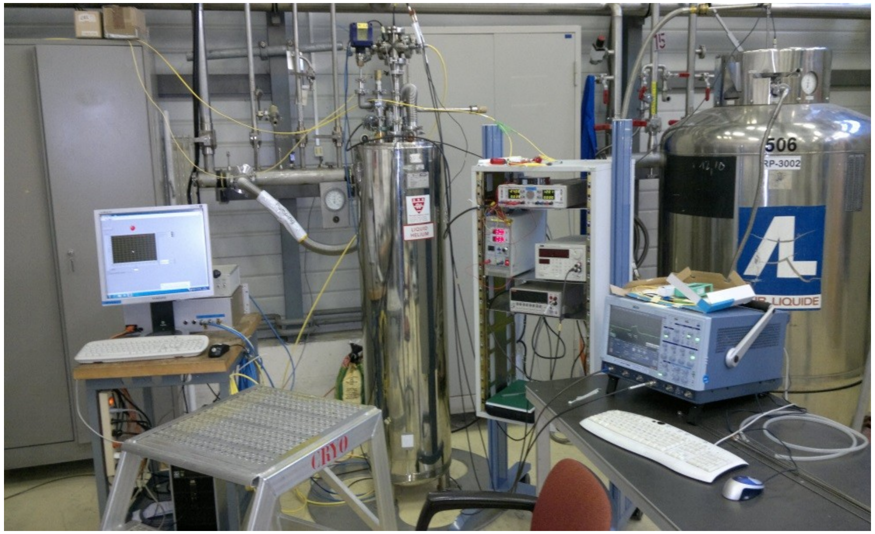
• Resistivity tends 80k Ωcm > 40k Ωcm during high temperature oxidation.

• This is probably (but nobody knows for sure) due to contamination by shallow level impurities incorporated during high temperature treatment.

Possible approaches to overcome the challenge







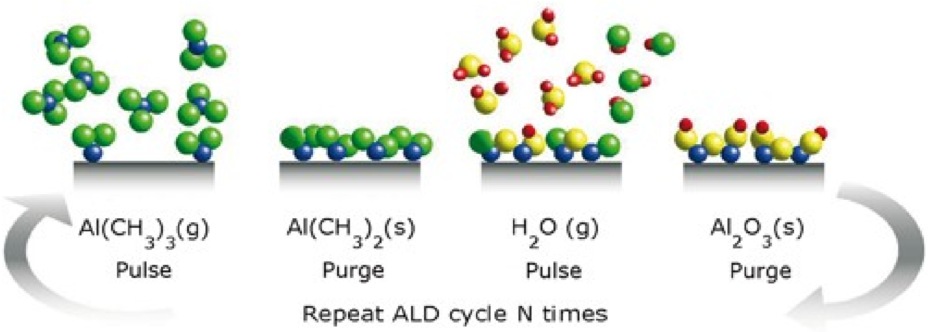
1) Passivation of Si at low temperature (e.g. 200-300°C)

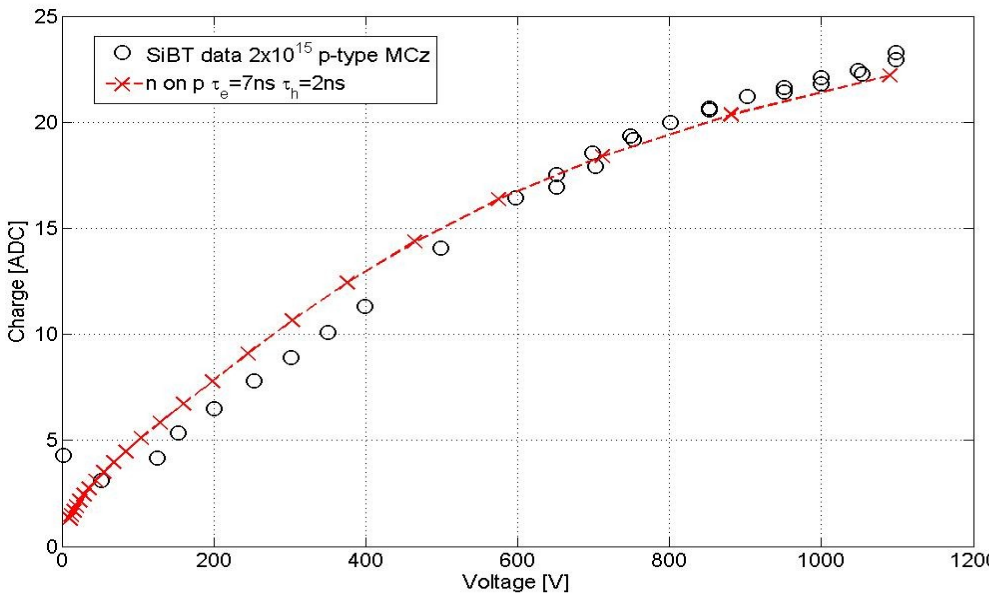
2) Compensation of p-type doping by oxygen thermal donors

3) Cryogenic operation

Passivation by Atomic Layer Deposition (ALD)

- ALD is a special case of more commonly adopted Chemical Vapor Phase Deposition thin film growth.
- ALD is based on successive, separated and self-terminating gas–solid reactions of typically two originally gaseous reactants, or precursors.
- Deposition on ALD thin films take place typically at 200-300°C.
- We have observed passivation (termination of surface recombination velocity) of silicon by ALD grown Ta_2O_5 comparable with thermally oxidized SiO_2

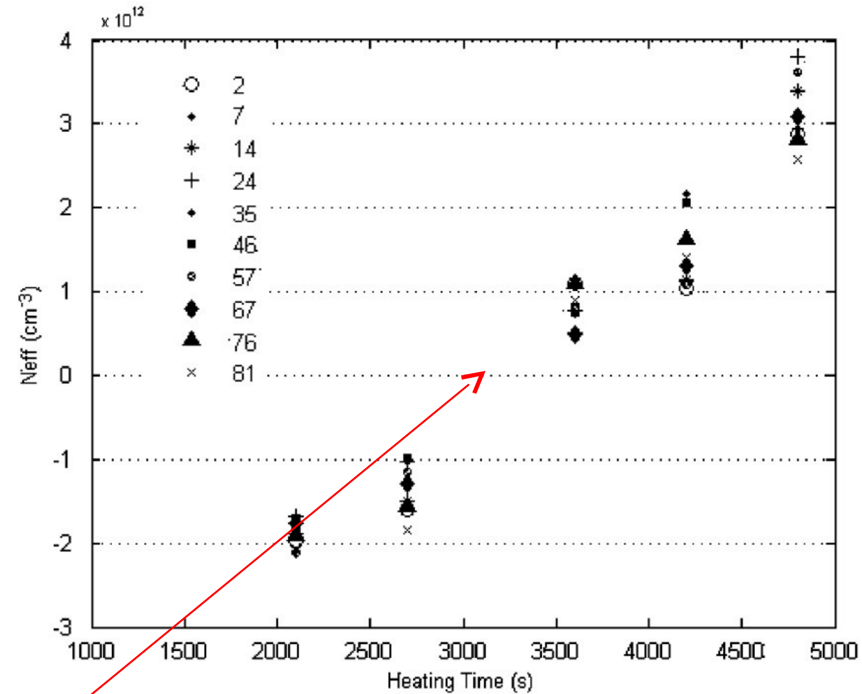




Test beam data from 2008. Measured sensor is full size strip detector with 768 channels attached into CMS APV25 readout board. The sensor is made of p-type MCz-Si and it was irradiated with 26 MeV protons in Karslruhe to fluence 2×10^{15} n_{eq}/cm^2 . Passivation was made by ALD grown Al_2O_3 field insulator. No p-stop/spray. The CCE at 600V is 42% and at 1100V 60% (full charge from reference planes is 40 ADC counts).

Oxygen donor compensation

- High oxygen content (present in MCz-Si materials) in Si results in Thermal Donor (TD) formation at temperatures at around 400°C.
- TDs are oxygen complexes that form shallow states in Si band gap below the conduction band.
- Effective resistivity can be adjusted in p-type MCz-Si in wide range.
- P-type Si can be type inverted into n-type.
- Prior the transition Si reaches intrinsic point



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MATERIALS SCIENCE IN SEMICONDUCTOR PROCESSING

Intentional thermal donor activation in magnetic Czochralski silicon

E. Tuovinen*, J. Härkönen, P. Luukka, E. Tuominen

Helsinki Institute of Physics, P.O. Box 64, 00014 University of Helsinki, Finland

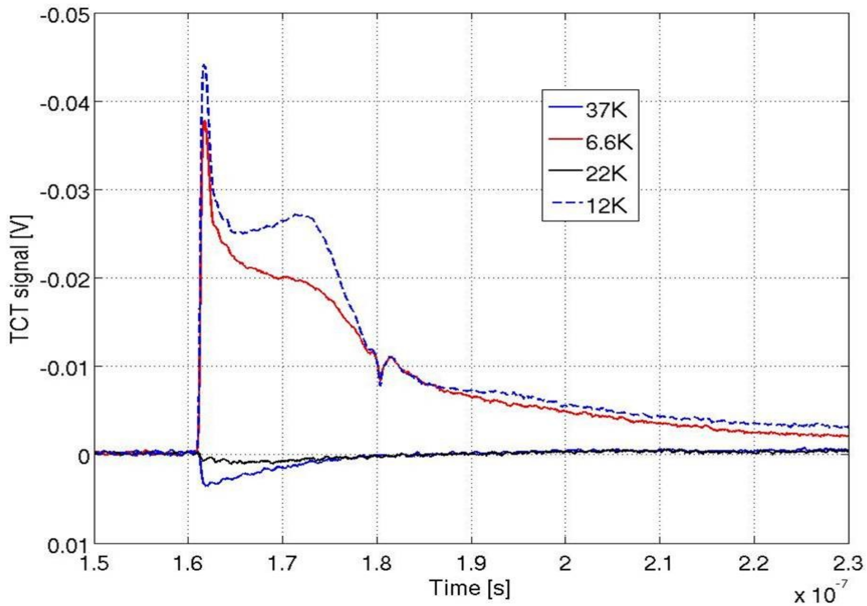
Available online 7 January 2008

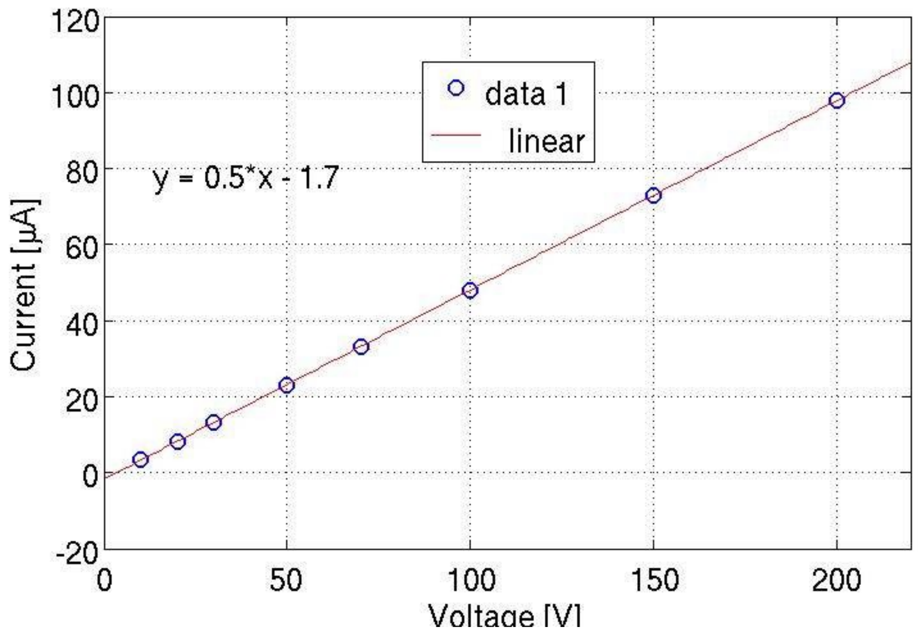
Abstract

We have made a quantitative study about the thermal activation of thermal donors in high resistivity magnetic Czochralski silicon. The thermal donor activation has been performed through a thermal treatment at 430 °C up to a total time of 80 min. The space charge density after each annealing step has been extracted from capacitance–voltage measurements. If the starting material is boron-doped p-type high-resistivity Czochralski silicon, the thermal donor generation process can be utilized in order to produce $p^+/n^-/n^+$ detectors. The last thermal process step, i.e. the sintering

Cryogenic operation

- At very low temperatures, dopants in Si freeze out and detectors show ohmic behavior.
- From BLM project we have observed that Si detector at 7K operating at CID mode Resistivity ≈ 17M Ωcm
- This is 50 times more than Si intrinsic resistivity at RT.
- Transition of signal polarity takes place at about 15K.
- Below transition temperature, detector is very strong and has long tail.
- Aegis vertexing favors for long pulse in order to obtain good timing resolution.
- What is the sensor operating temperature when Flip-Chip bonded into Timepix ROC ?





Summary

- Si detectors produces by RD39 are successfully tested in particle beams and by laser TCT setups
- Test beam data from December 2014 confirms functionality of Si BLM detectors.
- We have started activity to provide for AEgIS experiment thick Si pixel sensors, which would operate as time projection chamber.
- AEgIS silicon time projection chamber will operate at cryogenic temperature
- According to experience obtained from BLM project, RD39 expects that 2-3mm thick Si sensor could be operated at moderate bias voltage while simultaneously inducing very long signal allowing better time resolution.
- Thick Si sensor would provide societal impact in terms of e.g. X-ray detection in medical applications such a digital mammography or dental scanning.