RD39 status report 2015 - 2016

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

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Outline

- **Fields of activity and background**
- **Beam Loss Monitoring project:**

  - Status

  - Results of 2015 LHe *in situ* radiation beam test
- **First results on thick detectors development for AEgIS experiment**
- **Conclusions**
- **Future**

Background of RD39
for current and future developments

Research in the field of Radiation Hardness at cryogenic T

- **Lazarus effect (Carrier freezing on DL at 100 – 180K)**
- **Electric field manipulation by current injection**
- **Current injected detectors (CID)**

Current projects:

1. RD39 for HL-LHC - Silicon Beam Loss Monitors (BLM)

- **Physics of Si detectors operation in Superfluid Helium (SFHe, 1.9K)**
- **First BLM prototypes - fabrication and installation on the LHC magnets**
- **Advancing of BLM construction and technology**

2. RD39 for AEgIS (Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy) **experiment**

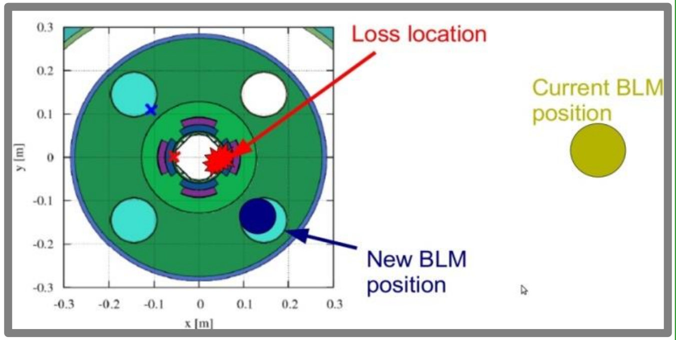
- **Thick (2 mm) Si cryogenic detectors**

Silicon BLM concept

Problem:
Existing BLM locate far away from the coils of LHC magnets; therefore they provide Low selectivity between particles hitting the magnets and debris

Solution: ***To place BLM sensor close to the magnet coil or integrate it in the coil construction***

Requirements to BLM sensor: *Compactness and appropriate radiation hardness*



Arguments to develop BLM on Silicon

1. *Compactness*
2. *Industrial base for mass-production*
3. *Expected reproducibility of characteristics*
4. *Cost effectiveness*

Results of cooperation between RD39 and CERN BE-BI-BL group

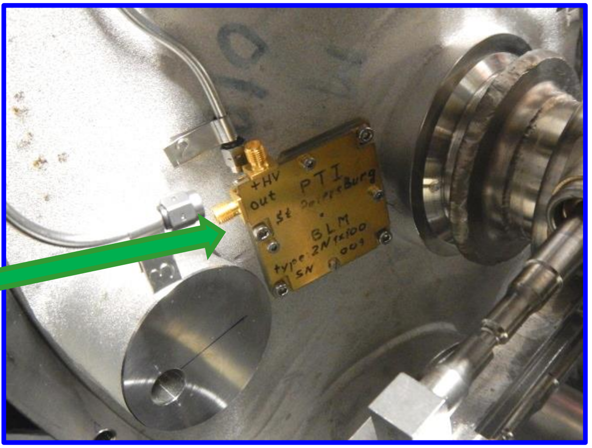
1. *Planning of experiments*
2. *Experiments preparation and participation*
3. *Development of cryo-BLM physics*
4. *New knowledge: physics of charge transport in silicon P-I-N structures at LHe T*

Milestones of BLM development

2012 – first test of Si PIN operation at 1.9 K: proof of concept

2012 – 1st *in situ* radiation test in SFHe: regular BLM

2014 – 2nd *in situ* radiation test in SFHe : thin BLM
first Si BLM modules installation



2015 – 3rd *in situ* radiation test in SFHe: statistics

Goals of BLM development in 2015

Proof of concept → Structure optimization + Statistics

⇩

Regular detectors (W = 300 μm)

⇩

Thin bulk detectors (100 μm)

⇩

Thin bulk detectors (100 μm)
with I-V stabilization structure

Results of the 2nd *in situ* irradiation test

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CERN-RD39 collaboration activities aimed at cryogenic silicon detector application in high-luminosity Large Hadron Collider

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A R T I C L E I N F O

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Beam loss monitoring
Superfluid helium
Silicon detector
Radiation hardness
Charge collection

A B S T R A C T

Beam Loss Monitors (BLM) made of silicon are new devices for monitoring of radiation environment in the vicinity of superconductive magnets of the Large Hadron Collider. The challenge of BLMs is extreme radiation hardness, up to 10^{16} protons/cm^2 while placed in superfluid helium (temperature of 1.9 K). CERN BE-BI-BL group, together with CERN-RD39 collaboration, has developed prototypes of BLMs and investigated their device physics. An overview of this development—results of the *in situ* radiation tests of planar silicon detectors at 1.9 K, performed in 2012 and 2014—is presented. Our main finding is that silicon detectors survive under irradiation to 1×10^{16} p/cm^2 at 1.9 K. In order to improve charge collection, current injection into the detector sensitive region (Current Injection Detector (CID)) was tested. The results indicate that the detector signal increases while operated in CID mode.

In situ irradiation test in 2015 (3rd *in situ* test)

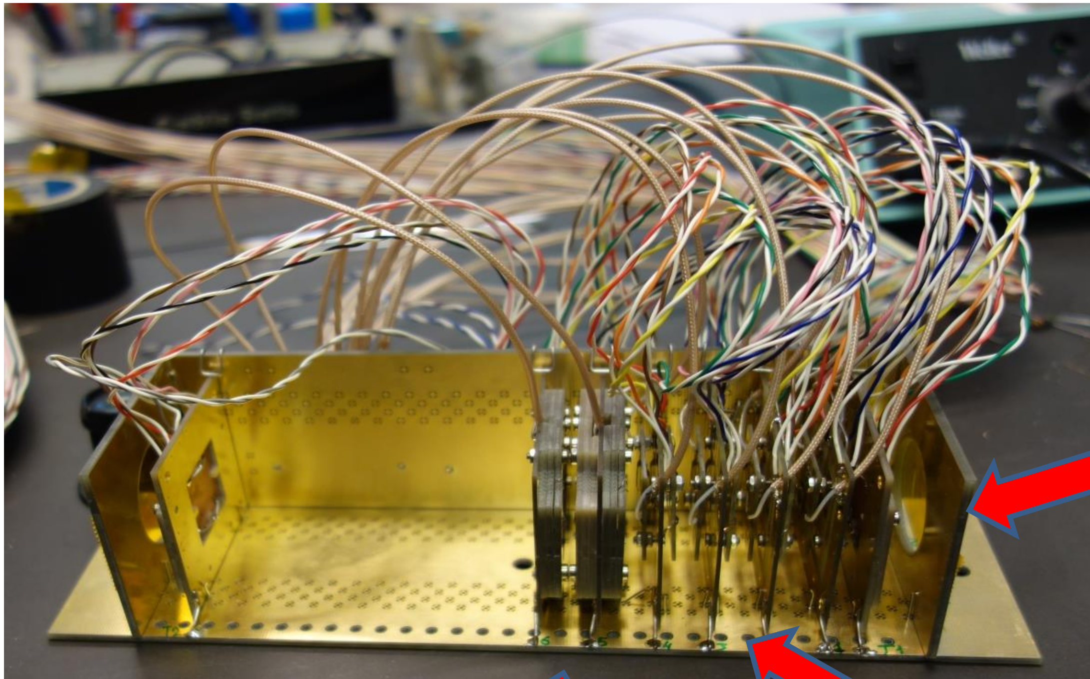
Set of modules with Silicon detectors

module	detector amount	material	thickness (um)	area, metallization	operational voltage	purpose
Tele-IN	4	Si, >15kΩ cm	300	12x12 mm2, solid	200 V	Telescope "IN"
MM-1	4	Si, >15kΩ cm	300	5x5 mm2, solid	400 V	statistics
MM-2	4	Si, 0.5 kΩ cm	300	5x5 mm2, solid	500 V	statistics
MM-3	4	Si, >15kΩ cm	**100**	5x5 mm2, solid	500 V	statistics
MM-4	4	Si, >15kΩ cm	**100**	5x5 mm2, solid	400 V	statistics
TCT-1	1	Si, >15kΩ cm	300	5x5 mm2, grid	400 V	CERN-DAQ
TCT-2	1	Si, >15kΩ cm	300	5x5 mm2, grid	400 V	CERN-DAQ
Spare	0					
Spare	0					
TeleOUT	4	Si, >15kΩ cm	300	12x12 mm2, solid	200 V	Telescope "OUT"

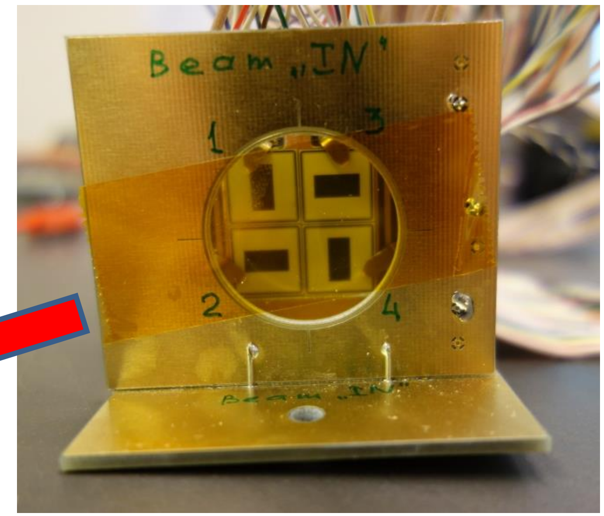
TOTAL detector amount – 26 pcs.

Detectors are processed by consortium of the Ioffe Institute and Research Institute of Material Science and Technology (Zelenograd), both Russia

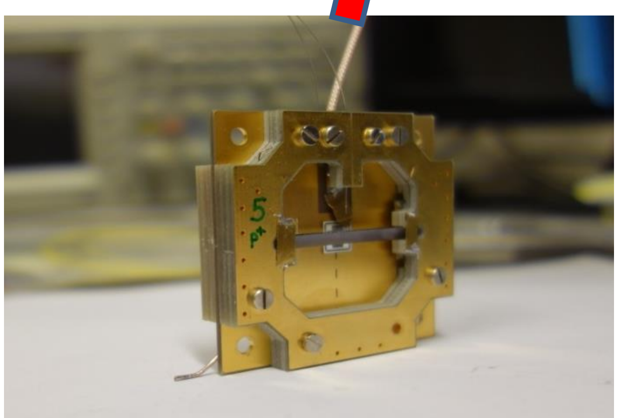
Cassette for detectors irradiation



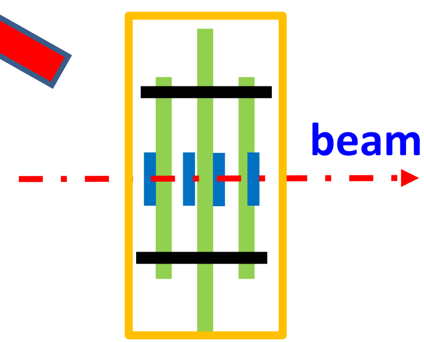
Telescope module



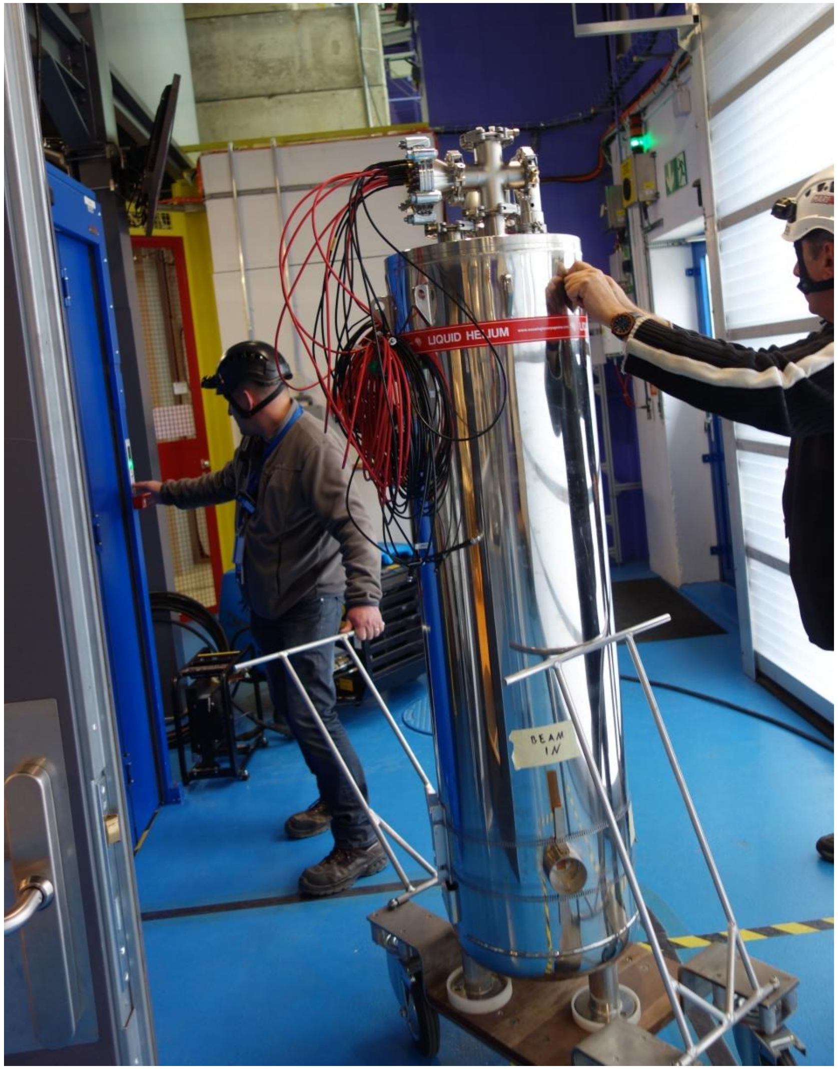
TCT module



Multi-module construction



Installation of cryostat at CERN PS irradiation facility



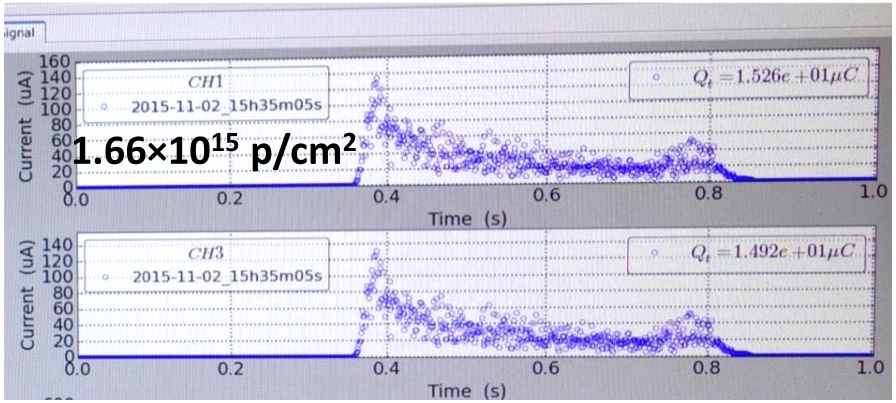
Electronics and data acquisition & processing

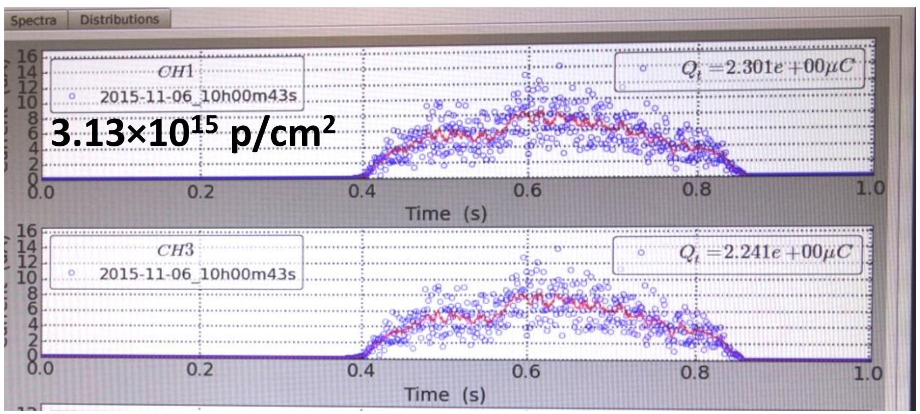
1. CERN-DAQ system
2. DAQ system of Ioffe Institute
   for statistical study

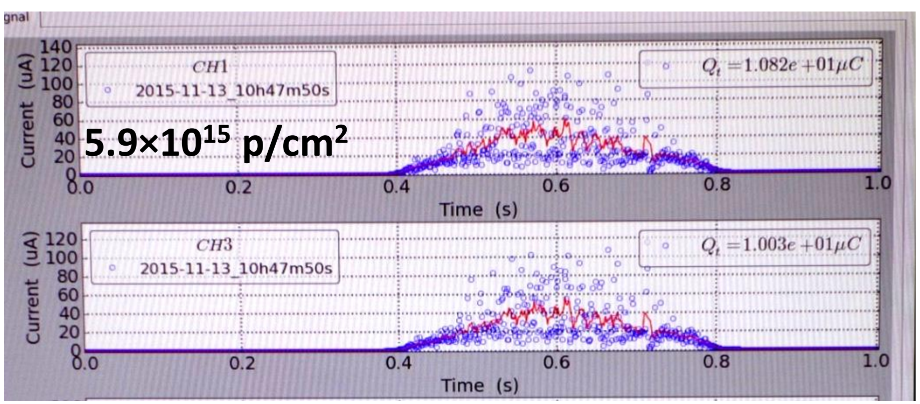
Permanent on-line registration during 3 weeks of experiment

16 inputs → Ampl → 16 channel sampling unit & ADC → Flash memory → Digital Trigger & DAQ → Hard disk

Detector signals from spills







- **Irradiation at CERN PS**
- **23 GeV protons**
- **Spill:**

  Duration - 400 ms

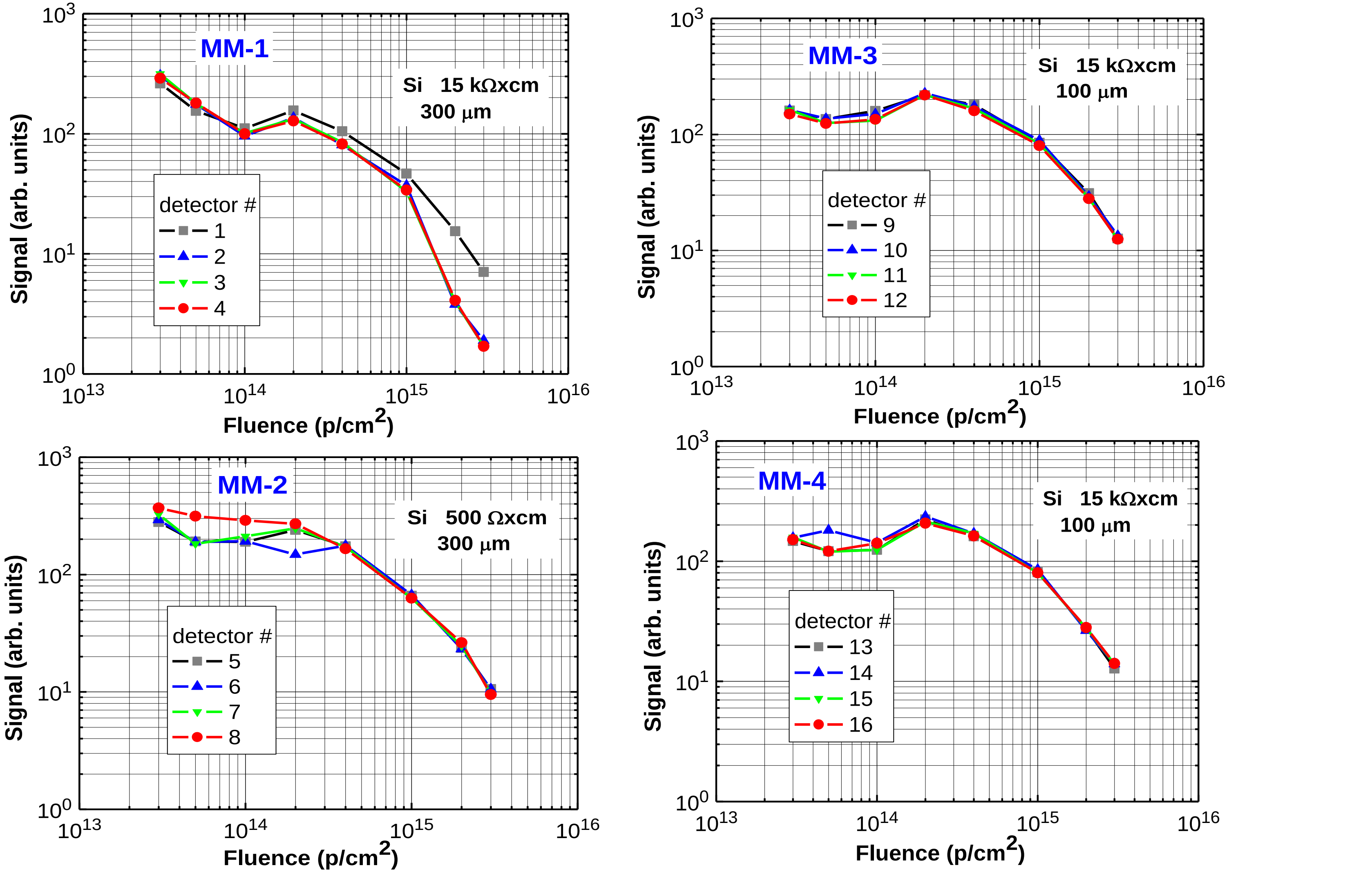
  Intensity - 6×10^{10} p/cm^2

Data from CERN-DAQ system
Detectors: TCT1, TCT2
W – 300 μm

Experimental data of *in situ* radiation test 2015

(preliminary, the worse case estimation)

Data from Ioffe DAQ system; 16 detectors from MM1-MM4



Challenge associated with very thick Si detectors

(thick Si detector for AEgIS providing 3D tracks)

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

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

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

• Thick Si sensors must be made of intrinsic (i.e. nondoped) silicon.

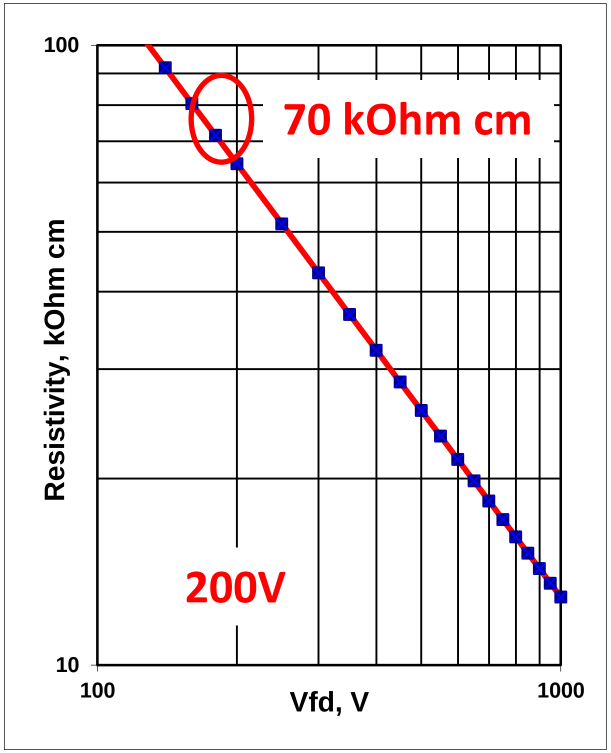
• **Fz-Si with resistivity ~80 kΩcm is commercially available.**

• **Normal detector processing includes several thermal oxidations of Si wafers at ~1100°C temperature.**

• **Resistivity tends 80 kΩcm to 40 kΩcm during high temperature oxidation.**

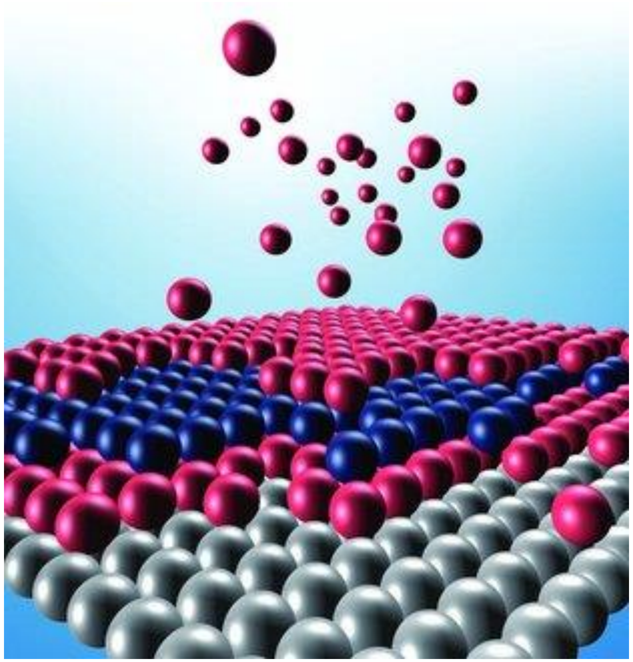
• **Bulk generated reverse current and V_{fd} rising.**

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

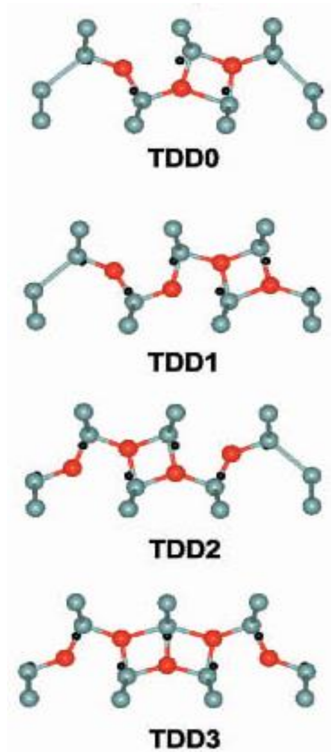


V_{fd} plot for 2 mm thick detector

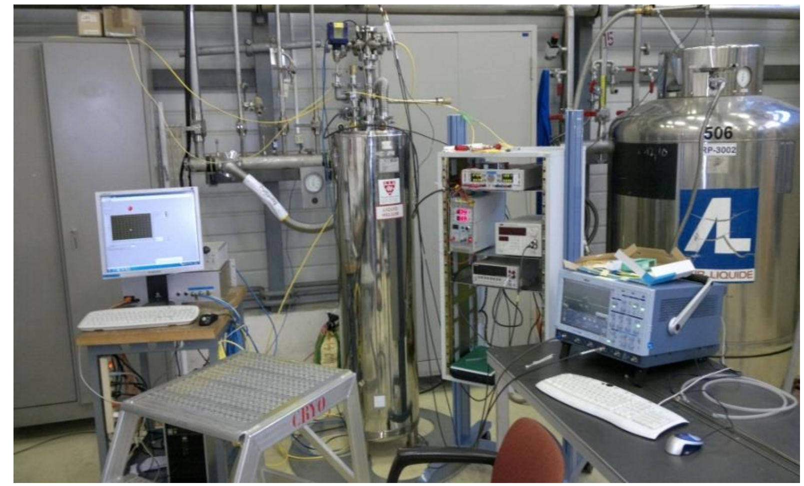
Possible approaches to overcome the challenge



1) Passivation of Si at low temperature (e.g. 200-300°C) **to minimize reduction of initial resistivity**



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

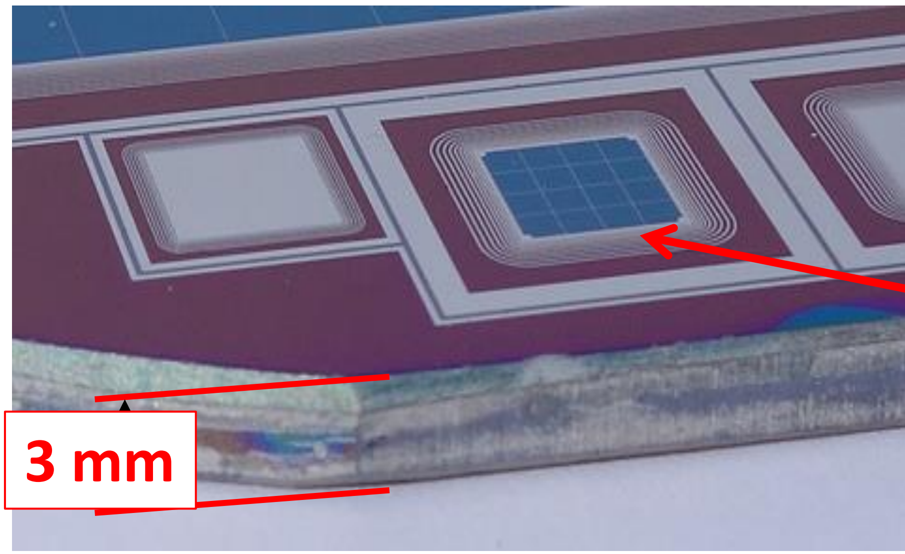


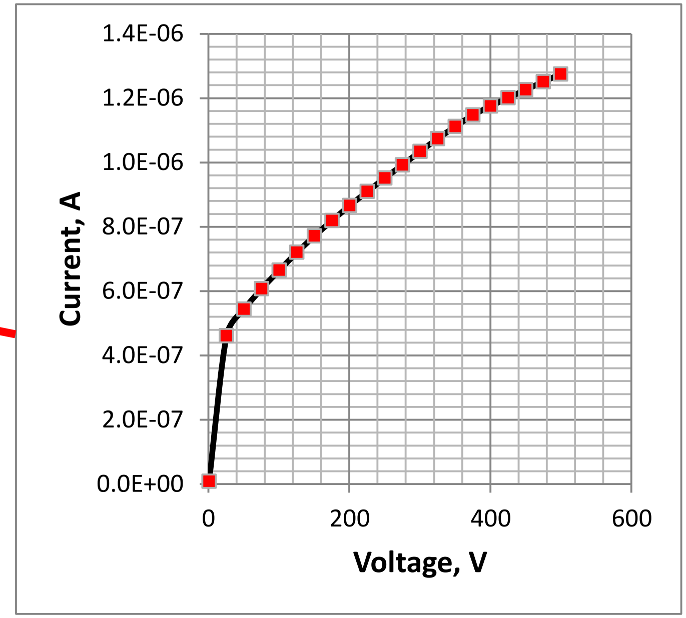
3) Cryogenic operation

to reduce bulk and surface current

- **The approach is under development utilizing the CVD/ALD technology,**
- **The results of first multipurpose run of 3 mm thick baby detectors is under analysis**

Fragment of 3 mm thick wafer with baby detectors processed in multi-purpose run





Initial material characteristics: resistivity - 75-80 kΩcm (V_{fd} = 400 V),
lifetime – 1 - 3 ms, (I_{rev} = 6e-7 -- 2e-7/ A/cm²

In processed detector :

- **Active area – 8 x 8 mm²**
- **Initial resistivity reduced to 56 kΩcm (V_{fd} = 550 V) !!!**
- **The leakage current increased up to 4 times, cooling can make it negligible**

Conclusions

- The identity of silicon BLM detectors (identical signals vs. fluence curves) is well visible over each detector group
- The implemented I-V stabilization structure in 100 μm detectors is effective up to 400V.
- Minimal deviations of detector sensitivity are observed for 100 μm groups (MM-3 and MM-4). Deviation is less than 10%.
- The lowest rate of degradation is observed for 100 μm detectors.

Future plans

1. Continue the treatment of *in situ* cryogenic beam test-2015 data to derive effective critical parameters
   - the parameters will be included in development of long-term degradation scenario of Si detectors operation as BLMs.

2. Prototyping of silicon BLMs using thin (50 – 20 μm) membrane technology
   - provides extension of operational fluence to the range of 10^{16} n_{eq}/cm^2.

3. Continue development of thick Si detectors for cryogenic application (AEgIS experiment)
   - perform baby detectors testing at LHe temperature.