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Progress in MAGNEX focal plane detector

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NUMEN project@LNS

Nuclear Matrix Elements of Neutrinoless Double Beta Decays by Heavy Ion Double Charge Exchange Reactions

Cappuzzello Talk

$$[T_{1/2}]^{-1} = G_{0\nu} |M_{0\nu}|^2 |f(m_i, U_{ei})|^2$$

$0\nu\beta\beta$ decay rate $[T_{1/2}]^{-1}$ can be factorized as a phase-space factor $G_{0\nu}$, the nuclear matrix element (NME) $M_{0\nu}$ and a term $f(m_i, U_{ei})$ containing the masses m_i and the mixing coefficients U_{ei} of the neutrino species

The DCE (^{18}O,^{18}Ne) reaction as a probe for the $\beta^+\beta^+$ transitions and the (^{20}Ne,^{20}O), or alternatively the (^{12}C,^{12}Be), for the $\beta^-\beta^-$

^{12}C, ^{18}O, ^{20}Ne to energies between 15 and 30 MeV/u

Experimental Setup:
CS beam –MAGNEX magnetic spectrometer

Major upgrade of LNS facilities

- The **CS accelerator** upgrades current from 100 W to 5 - 10 kW
- The **MAGNEX -focal plane detector** will be upgraded from 2 khz to 500 khz

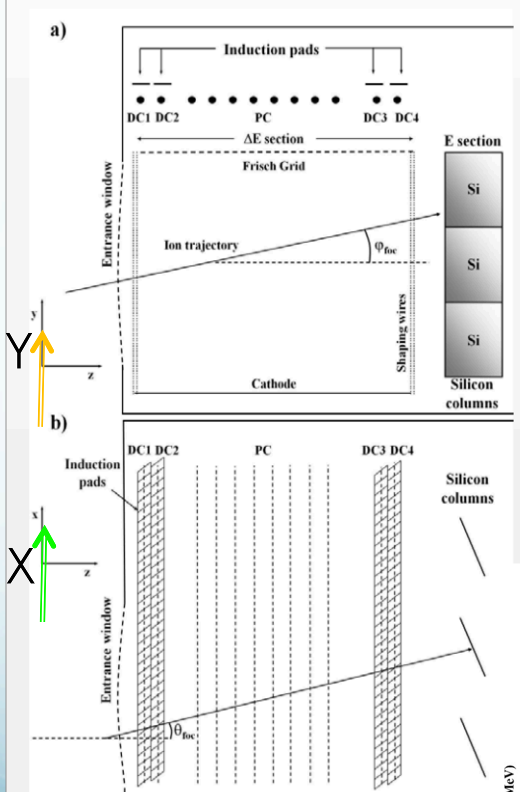
Focal Plane Detector

- Gas-filled hybrid detector

Drift chamber 1400mm x200mmx100mm
Pure isobutane pressure range: 5-100mbar; 600-800 Volt,wires 20 micron

- Wall SI 500 μm

20 columns, 3 rows



60 Silicon Detectors
→ E_{res}

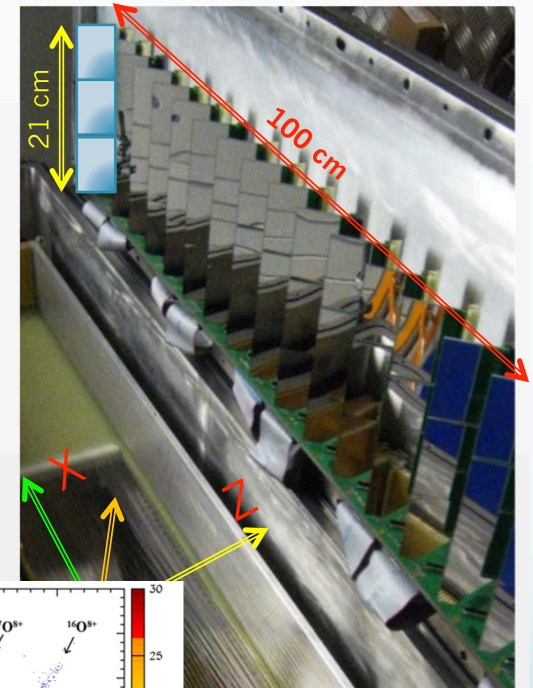
5 Proportional Wires
→ ΔE

Ion identification

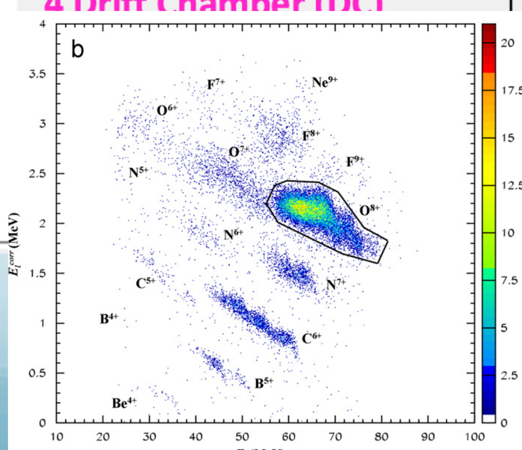
4 Induction Strip
→ X_1, X_2, X_3, X_4
→ X_{foc}, θ_{foc}

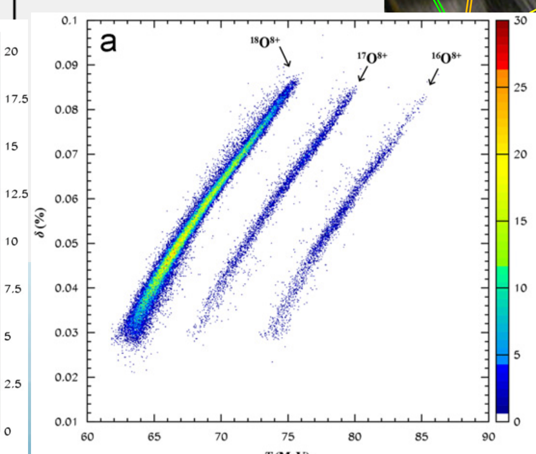
Ray-reconstruction

4 Drift Chamber (DC)



stopping 7 X 5 cm²
ctors surface covered
00 X 21) cm²



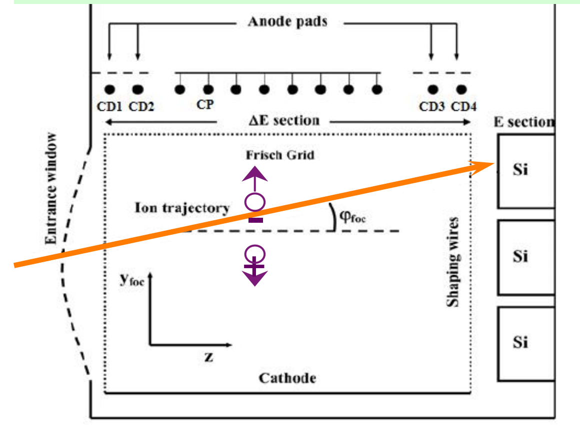


Cavallaro et al.Eur. Phys. J. A (2012) 48: 59
DOI 10.1140/epja/i2012-12059-8

F. Cappuzzello et al. / Nuclear Instruments and Methods in Physics Research A 621 (2010) 419–423

Upgrade of Focal Plane Detector

Multiwire gas trackerand ΔE stage



Limited to 1-2 kHz
It is necessary change system!

Wall of 60 Silicon detectors

Double-hit probability at 500 kHz > 30%
A much higher granularity is necessary!!!

We must change detectors

500 kHz

From Multiwire gas tracker → to gas tracker based on micro-pattern amplifiers(no ΔE)

From 7 X 5 cm^2 silicon Wall → to telescopes (ΔE+E) wall with higher granularity and different materials

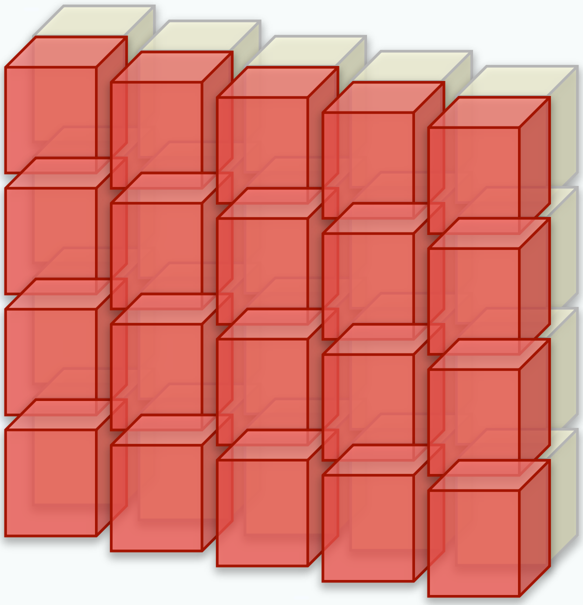
Radiation hardness

10^{14} ions/cm^2 in ten years of activity

Si detector dead @ 10^9 implanted ions/cm^2

PID requirements for NUMEN

- ✓ 1x1 cm^2 *ΔE-E* telescope
- ✓ thickness of *ΔE* stage 100 μm
- ✓ thickness of *E* stage 500-1000 μm
- ✓ hard to the radiation damage
- ✓ good energy resolution (1-2 %)
- ✓ High stability (electric and thermal)



RD50 - CERN

M.Moll , NIM in Physics Research A 511 (2003) 97–105

Property	Diamond	GaN	4H SiC	Si
E_g [eV]	**5.5**	**3.39**	**3.26**	**1.12**
$E_{breakdown}$ [V/cm]	10^7	$4 \cdot 10^6$	$2.2 \cdot 10^6$	$3 \cdot 10^5$
μ_e [cm^2/Vs]	1800	1000	800	1450
μ_h [cm^2/Vs]	1200	30	115	450
v_{sat} [cm/s]	$2.2 \cdot 10^7$	-	$2 \cdot 10^7$	$0.8 \cdot 10^7$
Z	6	31/7	14/6	14
ε_r	5.7	9.6	9.7	11.9
e-h energy [eV]	**13**	**8.9**	**7.6-8.4**	**3.6**
Density [g/cm3]	3.515	6.15	3.22	2.33
Displacem. [eV]	**43**	**≥15**	**25**	**13-20**

NUMEN

- Wide bandgap (3.3eV)

⇒ It has much lower leakage current than silicon

- Signal (**for MIP !**):

Diamond	36 e/μm
SiC	51 e/μm
Si	89 e/μm

⇒ It has more charge than diamond Si/SiC≈2

- Higher displacement than threshold silicon

⇒ radiation harder than silicon

Radiation hardness

Understanding radiation damage in solid state detectors is vital for the experiment NUMEN and future applications.

Defects in the semiconductor lattice **create energy levels in the band gap** between valence and conduction band.
Depending on the position of these energy levels the following effects will occur:

-**Modification of the effective doping concentration**

Shift of the **depletion voltage**.

caused by shallow energy levels (close to the band edges). –

-**Trapping of charge carriers**

reduced **lifetime** of charge carriers

Mainly caused by deep energy levels.

-**Easier thermal excitement of electron(-) and hole(+)**

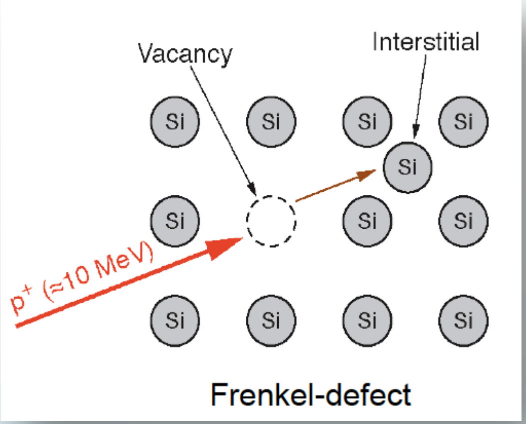
increase of the **leakage current**

Displacement

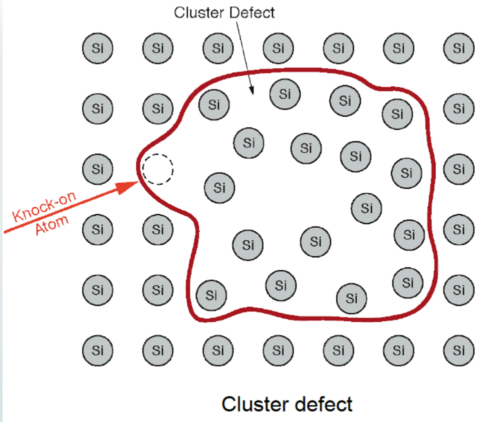
The minimum energy transfer in a collision to dislocate a silicon atom is $E_{min} \approx 15$ eV (depending on the crystal orientation).

The energy at which the dislocation probability in silicon is 50% is $E_d \approx$ 25 eV (displacement energy).

Below *Ed* only lattice oscillations are exited and no damage occurs.

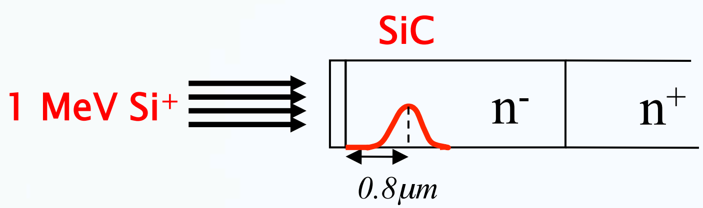


POINT DEFECT.
A vacancy-interstitial pair is called a Frenkel-defect.

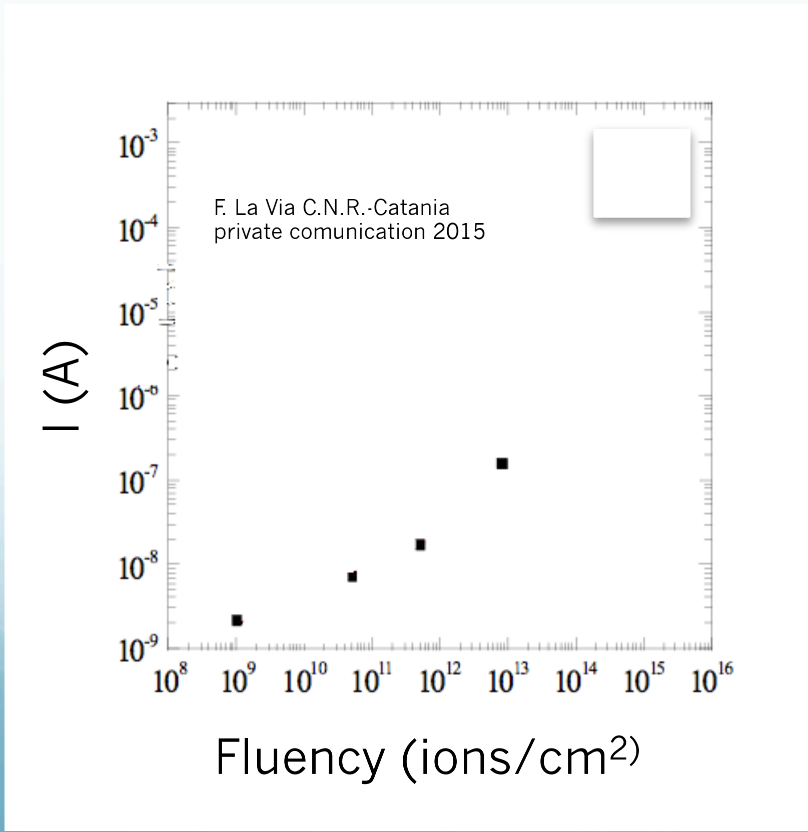


CLUSTER DEFECT
In hard impacts the primary knock-on atom displaces additional atoms. These defects are called cluster defects.

Radiation hardness



$\Phi = 1x10^9 – 1x10^{13}$ ioni/cm^2



$$I_{gen} \propto AWN_t T^2 e^{-\frac{(E_C - E_t)}{kT}}$$

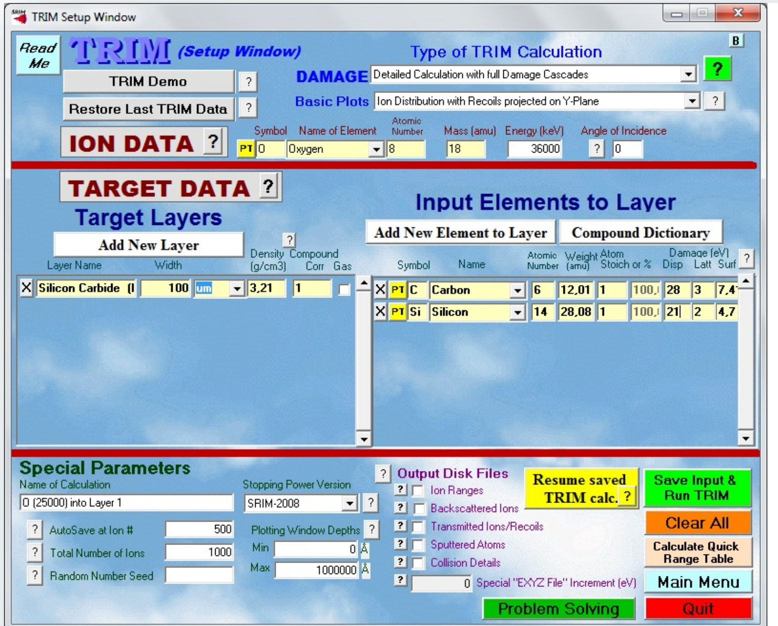
A= detector area
W=term related to the junction thickness
N_t=number of traps/defect
E_c=energy of conduction band
E_t=energy of trapping levels

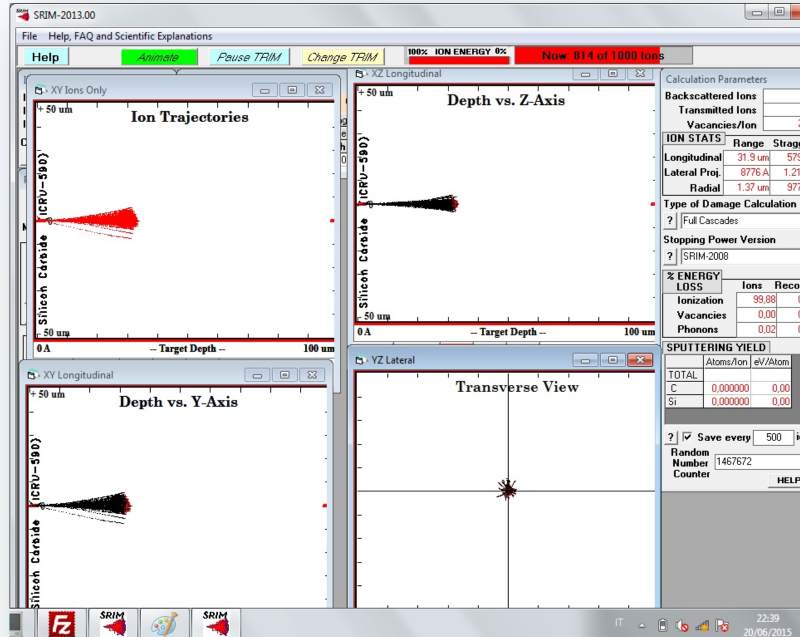
The generation current depends exponentially on the energy level E_t of the trapping level.

The levels in the mid-gap region are undesired and increase leakage current

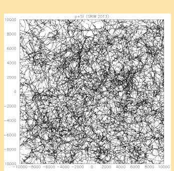
SiC are less sensitive to the radiation damage.

Displacementes by SRIM2013



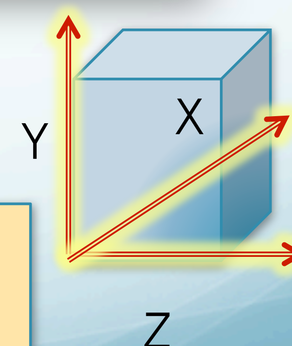


SRIM - The stopping and range of ions in matter (2010)
Volume 268, Issues 11-12, June 2010, Pages 1818-1823
James F. Ziegler | M. D. Ziegler | J. P. Biersack

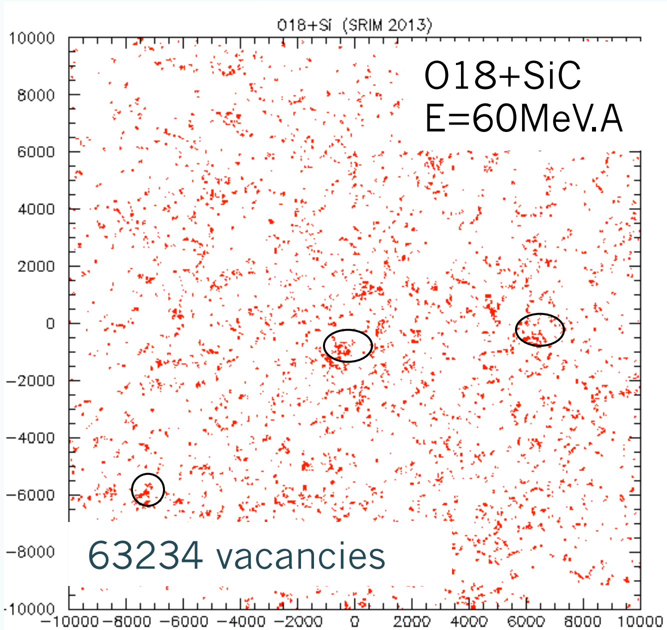


Data Analysis

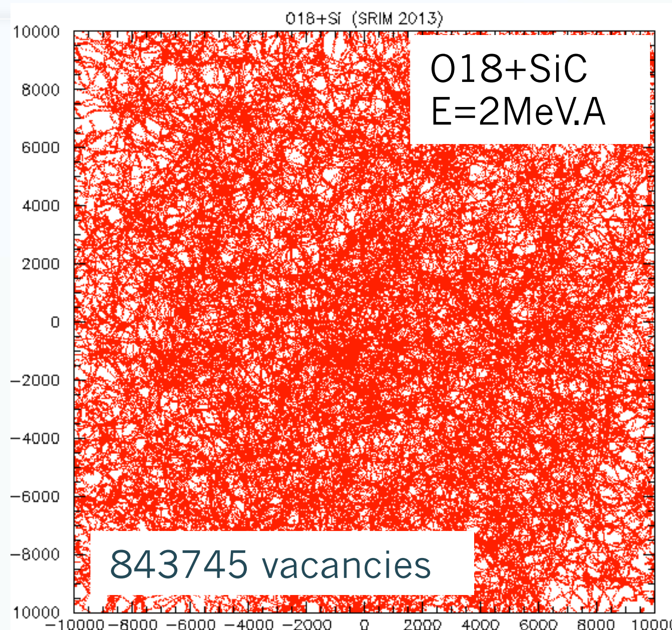
Random Localization on Detector Surface



Simulation (SRIM2013) of defect formation with radiation and diffusion.The simulations show the microscopic picture of defect distribution.



1μm * 1μm



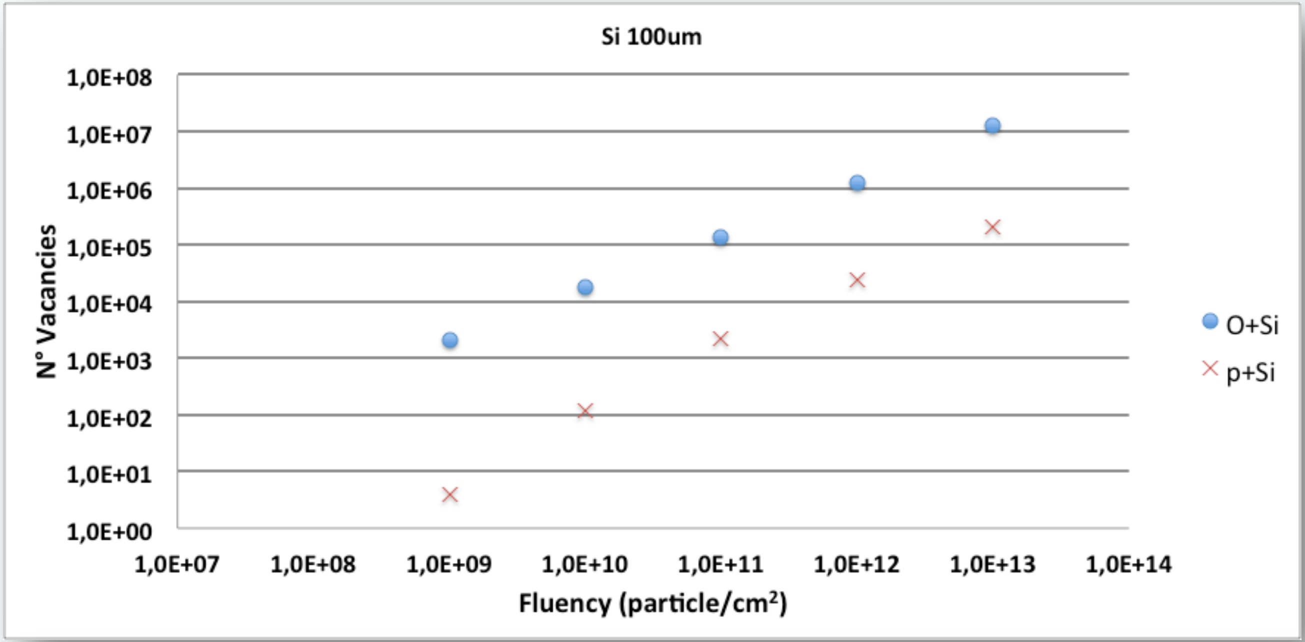
1μm * 1μm

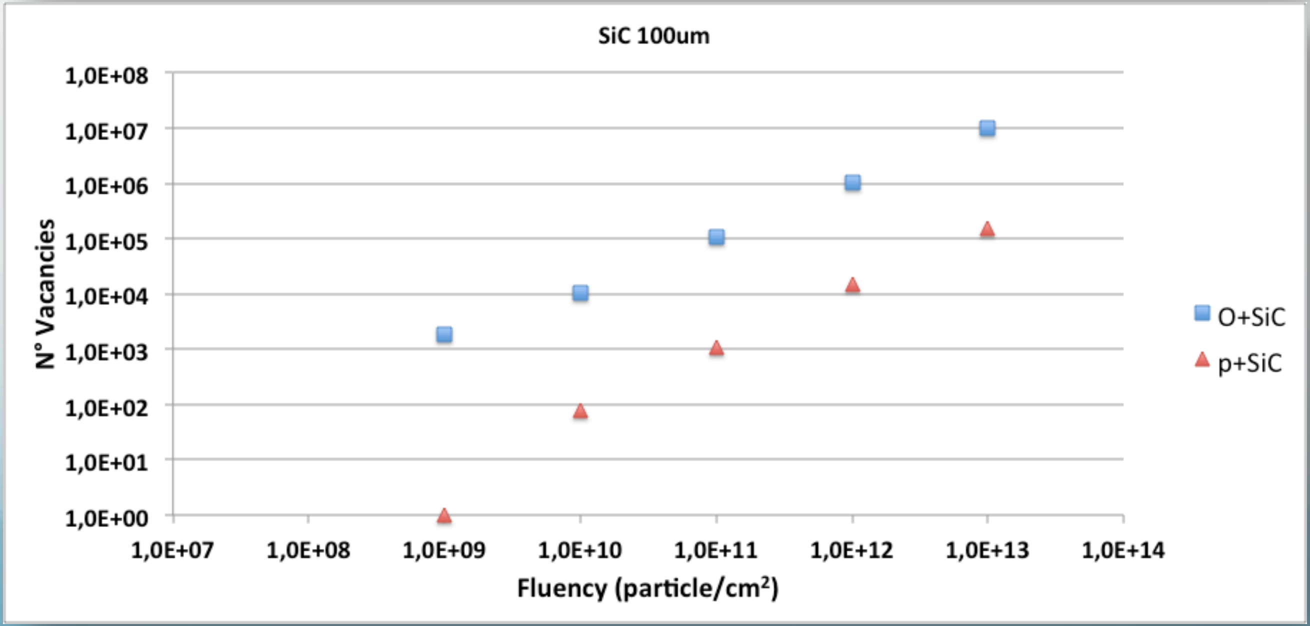
About 2MeV.A O18 produce a quite homogeneous vacancy distribution,

while more energetic with 60MeV.A form more cluster (circle) and discrete defects.

The plots are projections over 1μm ofdepth(z) and correspond to a fluence of 10^{14}part(MeV.A/cm^2)

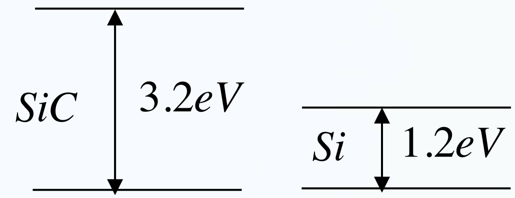
Vacancies on Si & SiC





Why SiC ?

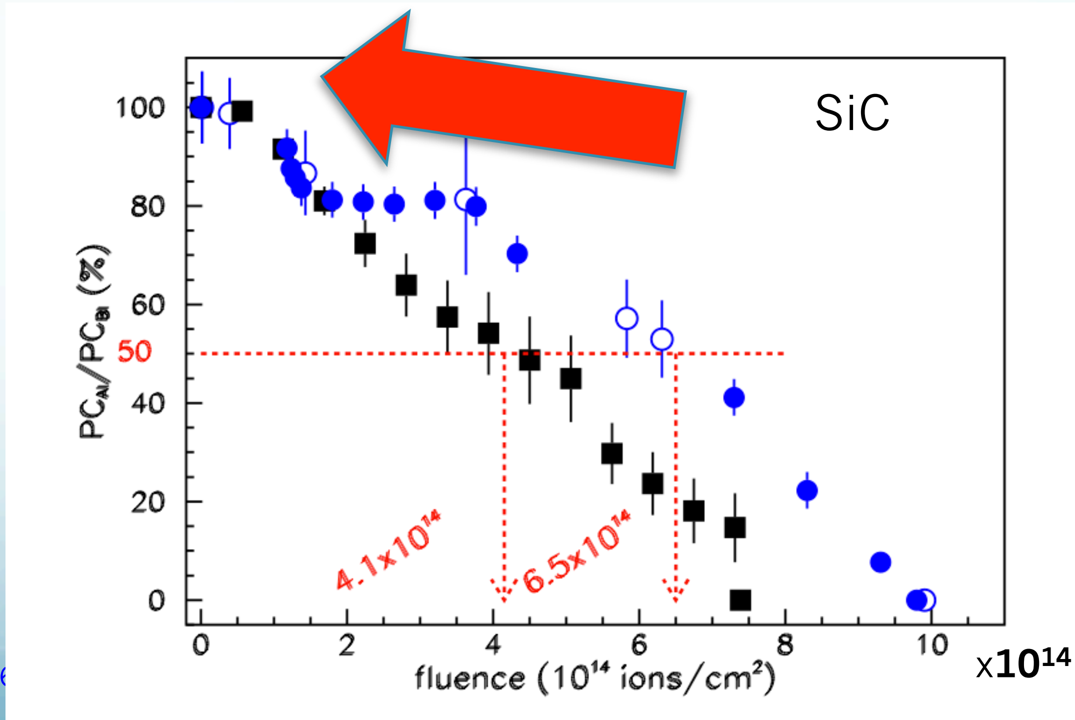
$$\frac{I_{gen}^{(SiC)}}{I_{gen}^{(Si)}} = \frac{N_t^{(SiC)} e^{-\frac{\left(E_C^{(SiC)} - E_t^{(SiC)}\right)}{kT}}}{N_t^{(Si)} e^{-\frac{\left(E_C^{(Si)} - E_t^{(Si)}\right)}{kT}}}$$



$$N_t^{(Si)} \approx N_t^{(SiC)}$$

$$I_{gen}^{(SiC)} \approx 10^{-5} I_{gen}^{(Si)}$$

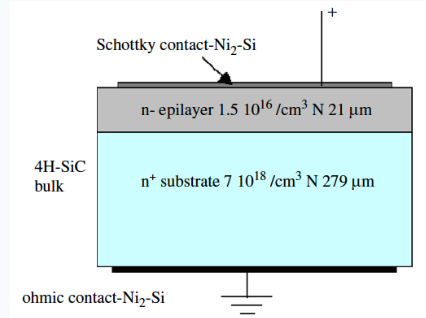
Two SiC were irradiated using ^{16}O ions at 35.2 MeV. The ratio between the peak centroid of the ^{16}O energy spectrum after the irradiation over the same peak centroid before the irradiation & fluence. It is evident that, by increasing the fluence, the energy peak, for both SiC moves toward lower channels, indicating an increasing incompleteness in the charge collection.



De Napoli et al.,NIM in Physics Research A 600 (2009) 618–6
Raciti et al. Nuclear Physics A 834 (2010) 784c–787c

SiC detector construction: state of art

The Schottky diodes are fabricated on epitaxyal layer grow onto high-purity 4H–SiC n⁻type substrate.



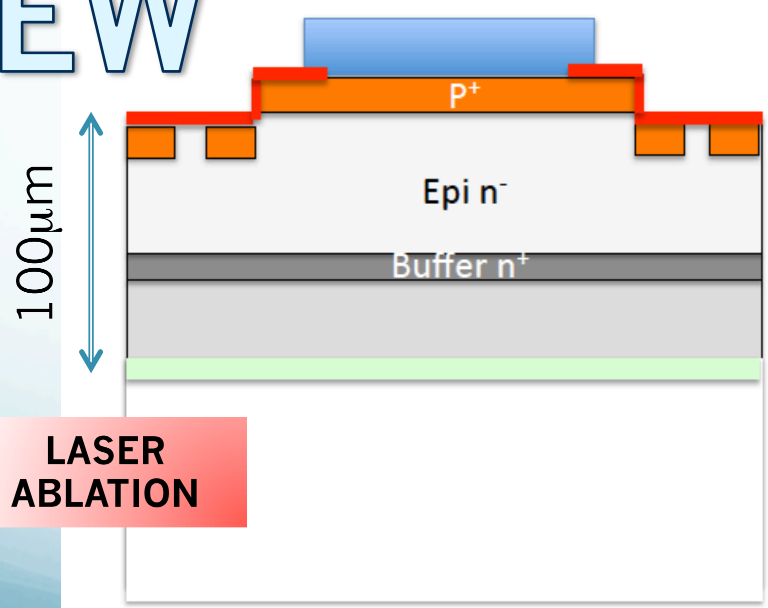
Detector Δ E

Detector E

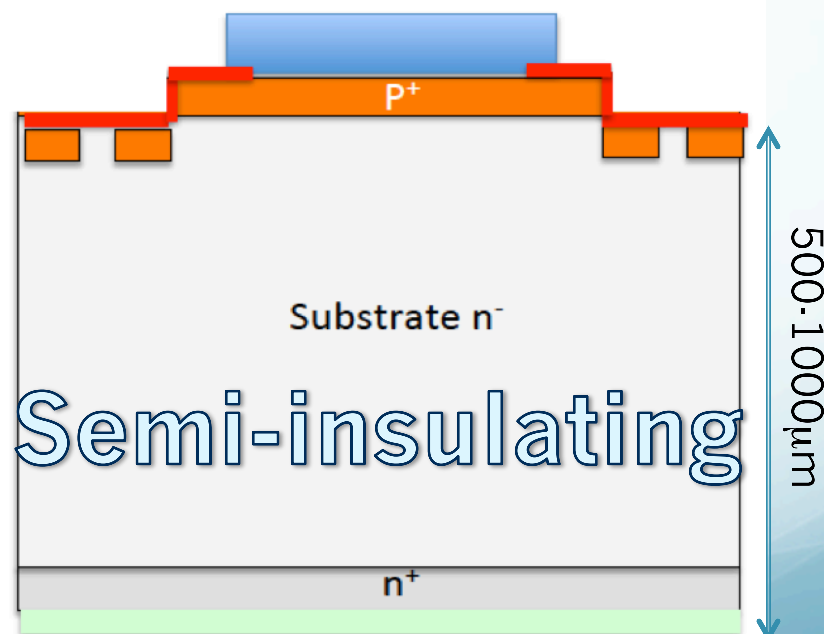
oxidation and metallization front

epitaxy of anode and cathode on intrinsic semi-insulating substrate

NEW

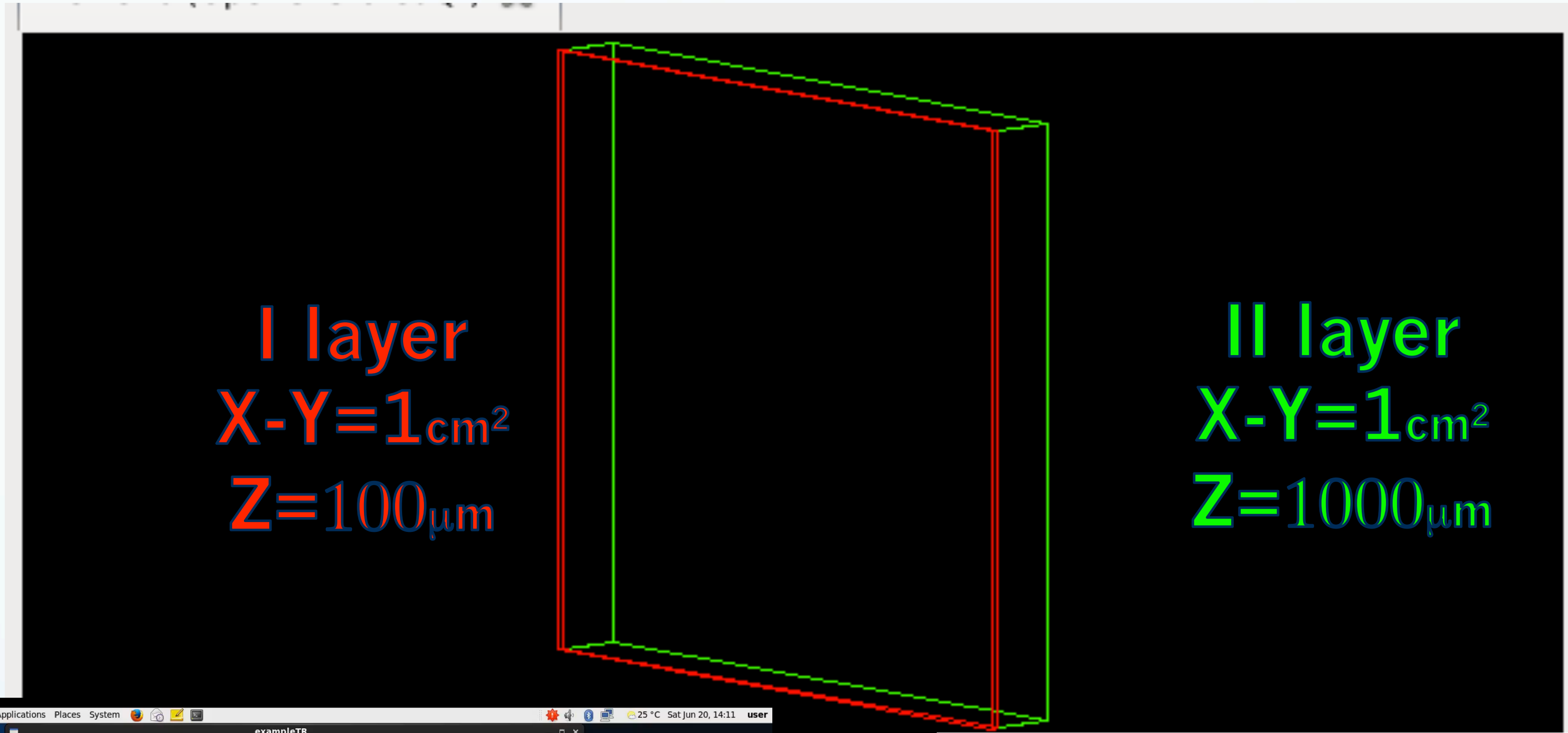


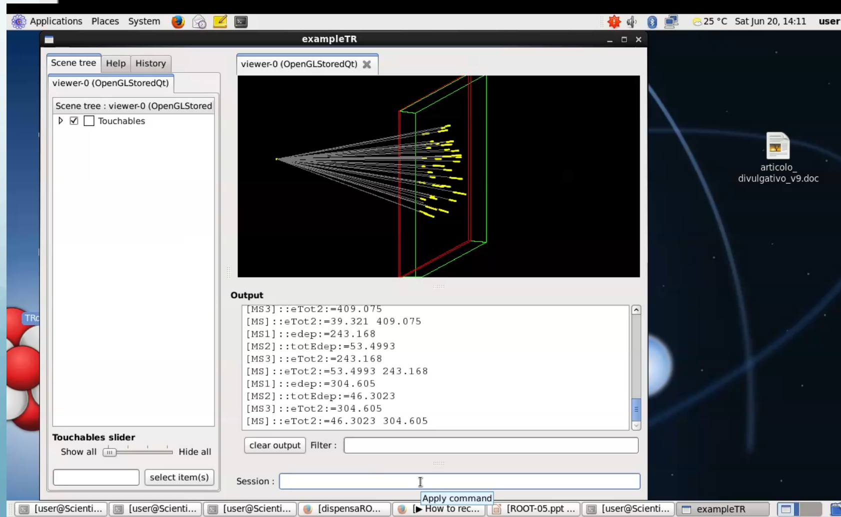
LASER ABLATION

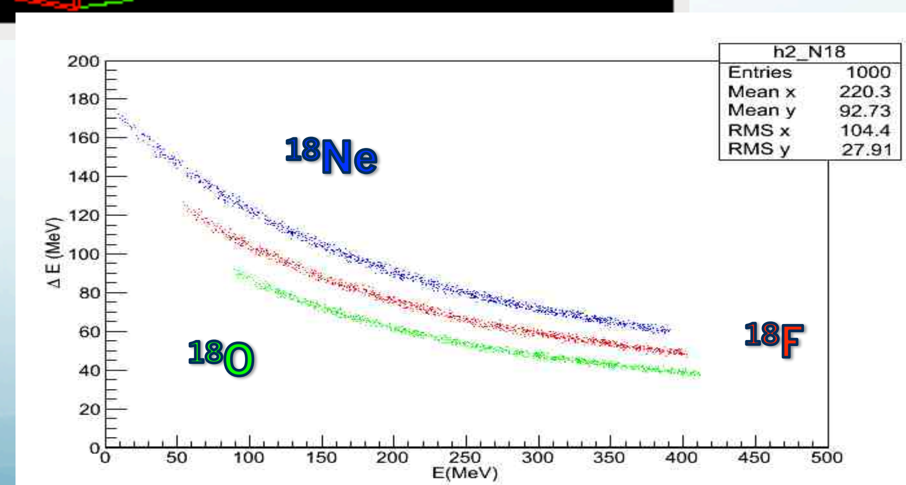


reduction thickness and metallization back

Detector telescope SiC with Geant4 simulation







Collaboration

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