Evaluation of the counting efficiency of a pcCVD diamond detector irradiated by 62 MeV/u carbon beams

F. Schirru[a], C. Nociforo[a], S. Schlemme[a,b], M. Kiš[a], J. Enders[b], C. Karagiannis[a], A. Kratz[a], M. Träger[a], R. Visinka[a]

[a]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

[b]Technische Universität Darmstadt, Darmstadt, Germany

GSI Helmholtzzentrum für Schwerionenforschung GmbH

Facility for Antiproton and Ion Research in Europe GmbH

15th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD19)

CVD Synthetic Diamonds

Synthetic diamond offers, over more conventional materials, a combination of unique properties which make it an attractive alternative for a wide range of applications in the field of X-, γ-rays and charged particle detection.

scCVD diamond samples

- Can be purchased with different thicknesses and area up to 1 cm^2
- Exhibit high purity and low dislocation concentration which leads to high mobilities and longer lifetimes of the charge carriers
- Show CCE (Qc/Qg) = 1

pcCVD diamond samples

- Are available in larger sizes (it allows to develop detectors having larger active areas)
- Have a larger amount of intrinsic defects (shorter lifetimes of the charge carriers)
- Show CCE (Qc/Qg) = 0.1 – 0.6*

*Particle intensity monitors based on pcCVD diamond samples may suffer from a reduction in their counting efficiency. Indeed, the partial CCE may generate signals having amplitudes below the threshold value of the discriminator.

The Goal

Key parameter under study is the counting efficiency ratio between a pcCVD and scCVD diamond detectors as a function of the beam intensity measured by a SEETRAM.

This study will allow to understand the dependence of the counting efficiency ratio respect to the following parameters:

- Beam Intensity
- Absorbed ions

Additional tasks:

- SEETRAM calibration with the SC-DD

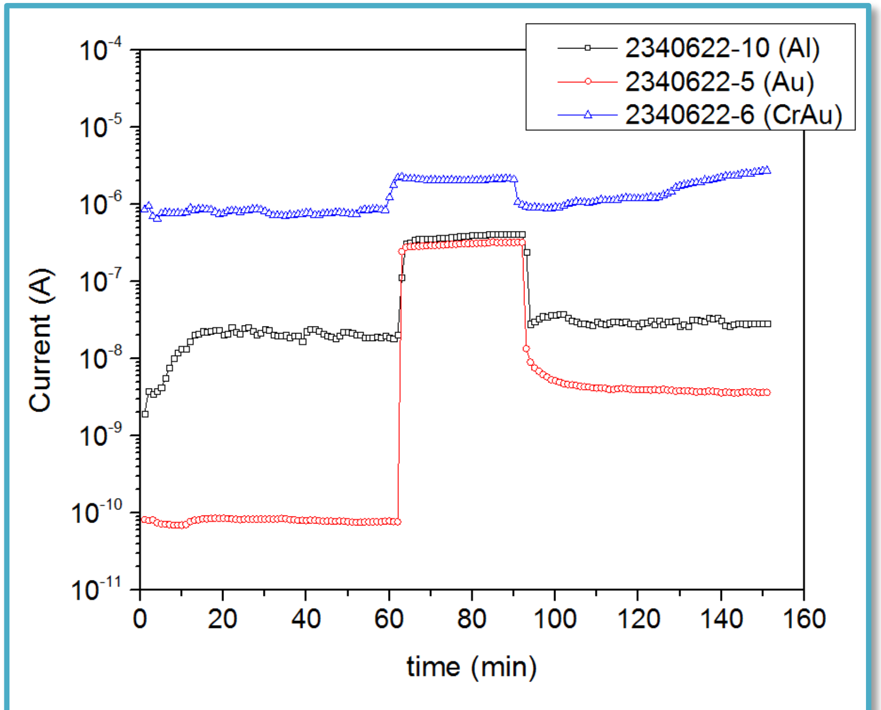
Diamond Detectors

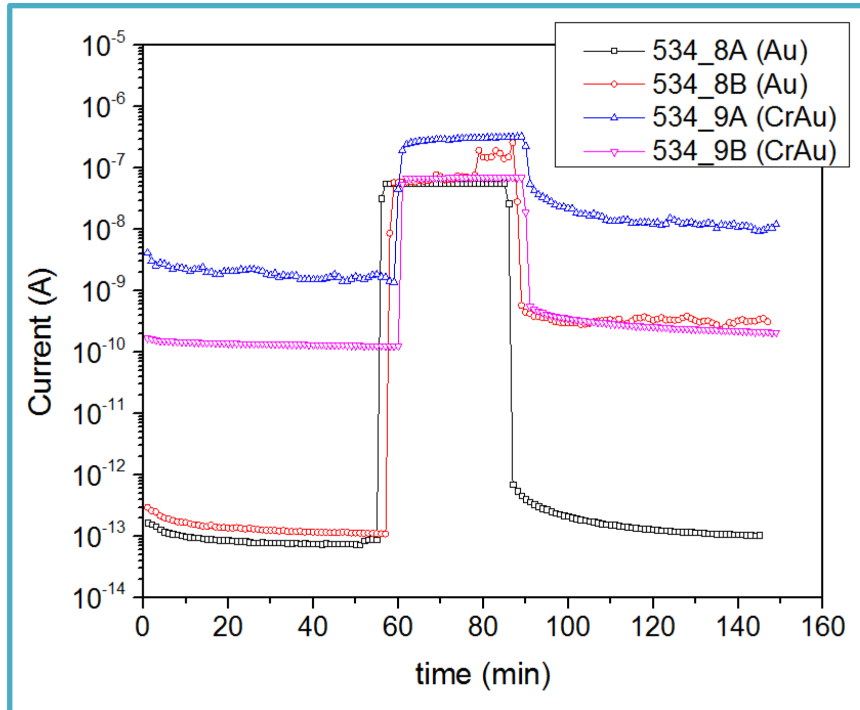
Sample	Type	Dimensions (mm^2)	Electrodes (nm), Type	Active Area (mm^2)
2340622-5	pcCVD	20 x 20 x 0.3	100, Au	18.5 x 18
2340622-6	"	"	50/100, Cr/Au	"
2340622-10	"	"	100, Al	"
534-8A	scCVD	4.2 x 4.2 x 0.16	100, Au	3.2 x 3.2
534-8B	"	"	"	"
534-9A	"	4.2 x 4.2 x 0.2	50/100, Cr/Au	"
534-9B	"	"	"	"

X-rays test settings

Distance (mm)	Tube Voltage (kV)	Tube Current (μA)	∅ Collimator (mm)
10	40	90	2 (Flux cone < 5°)

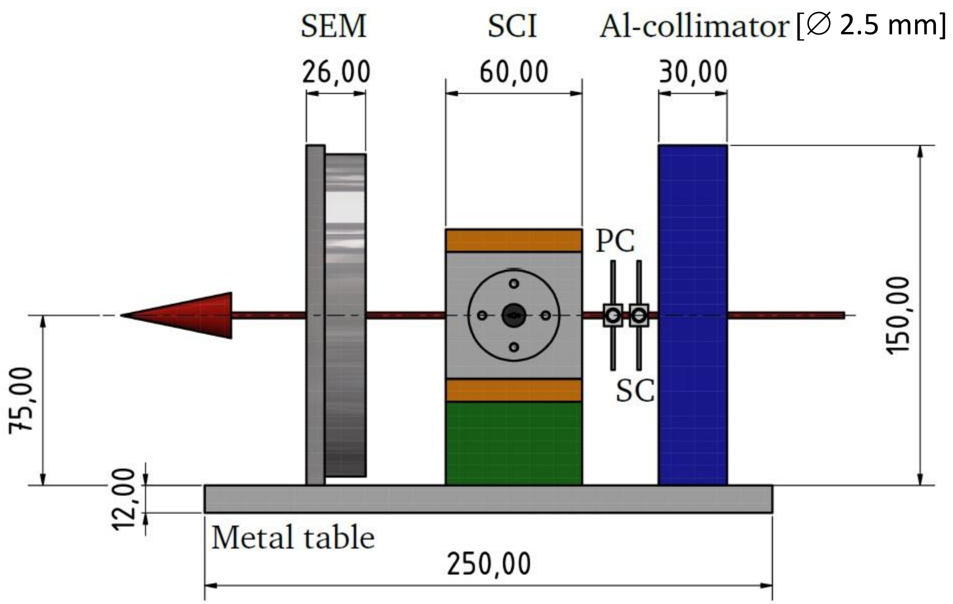
X-rays Tests (i)





- Electric field applied 1 V/μm on all devices
- Sensors show <u>different</u> *dynamic response*, *leakage current* and *signal-to-noise ratio* according to the electrodes type

Experimental Setup @LNS Facility



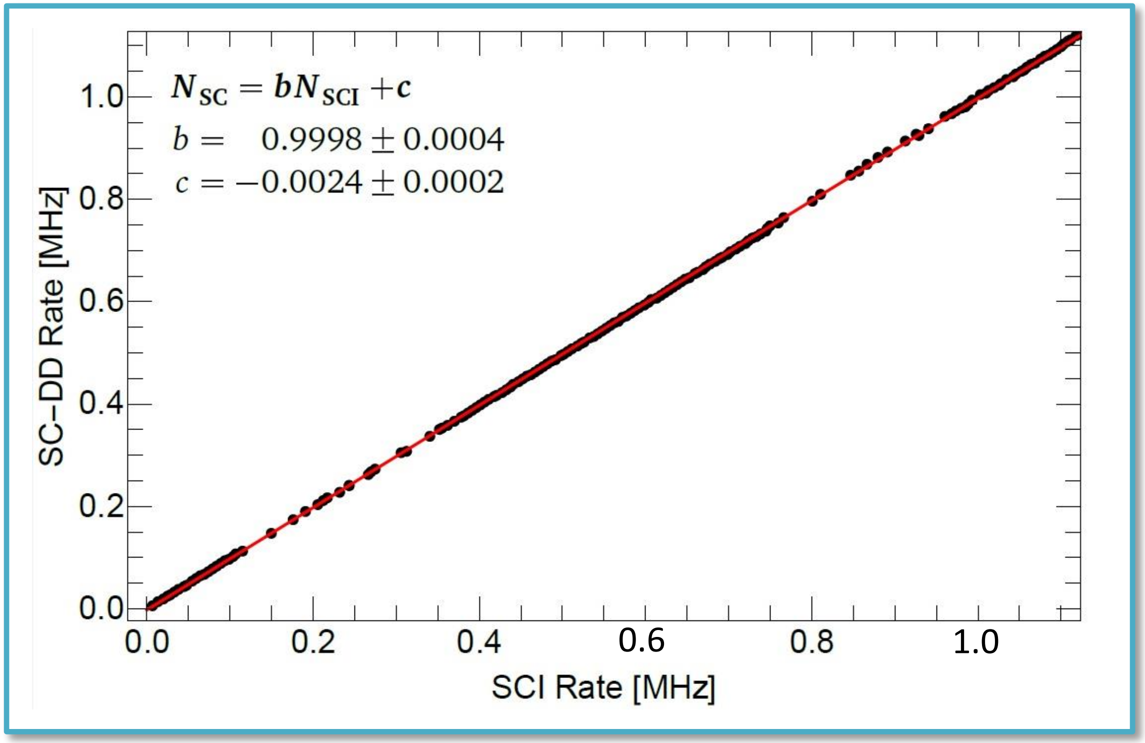
- Vacuum chamber integrated and aligned in the Zero Degree beam line
- No counting losses due to the detectors geometry [LISE++]

⇩

Direct comparison of the detectors performance (no correction factors introduced)

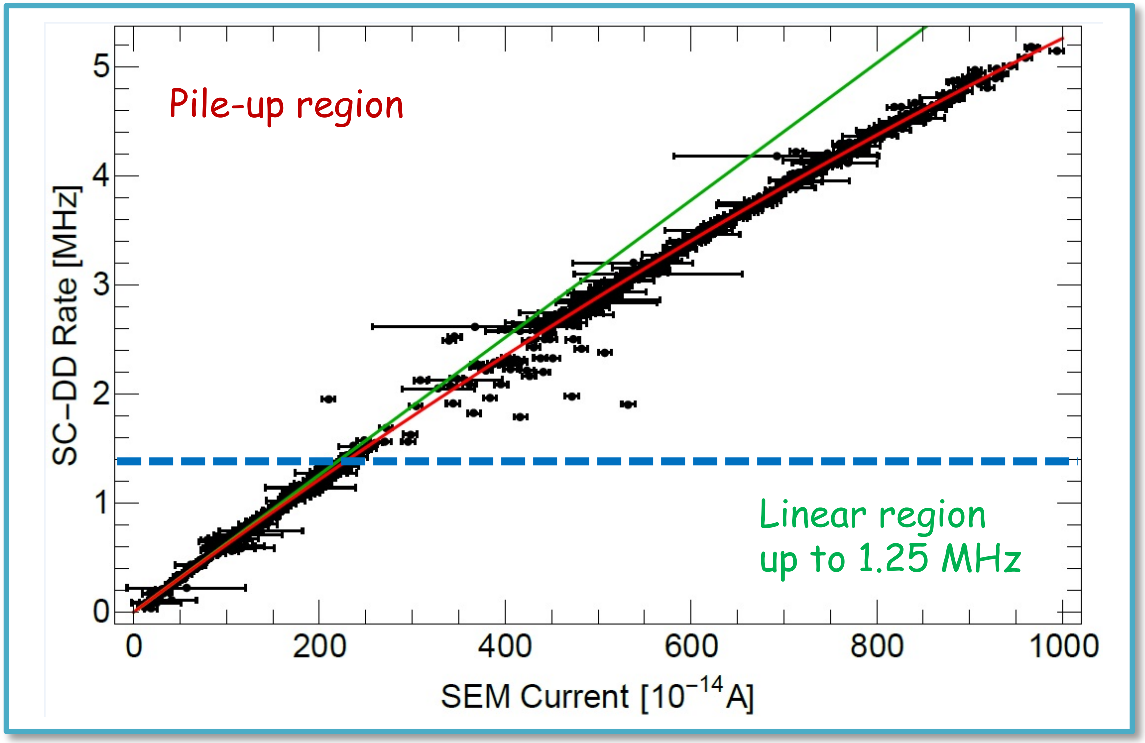
- Beam: fully stripped ^{12}C @62 MeV/u
- Intensity: variable [slits opening, attenuation factors (1, 10, 100, 1000)]

SC-DD Counting Efficiency Assessment



- Data collected at the beginning of the experiment
- Linear relationship up to 1.25 MHz [Slope coefficient: 0.9998 ± 0.0004]
- SC-DD shows 100% counting efficiency

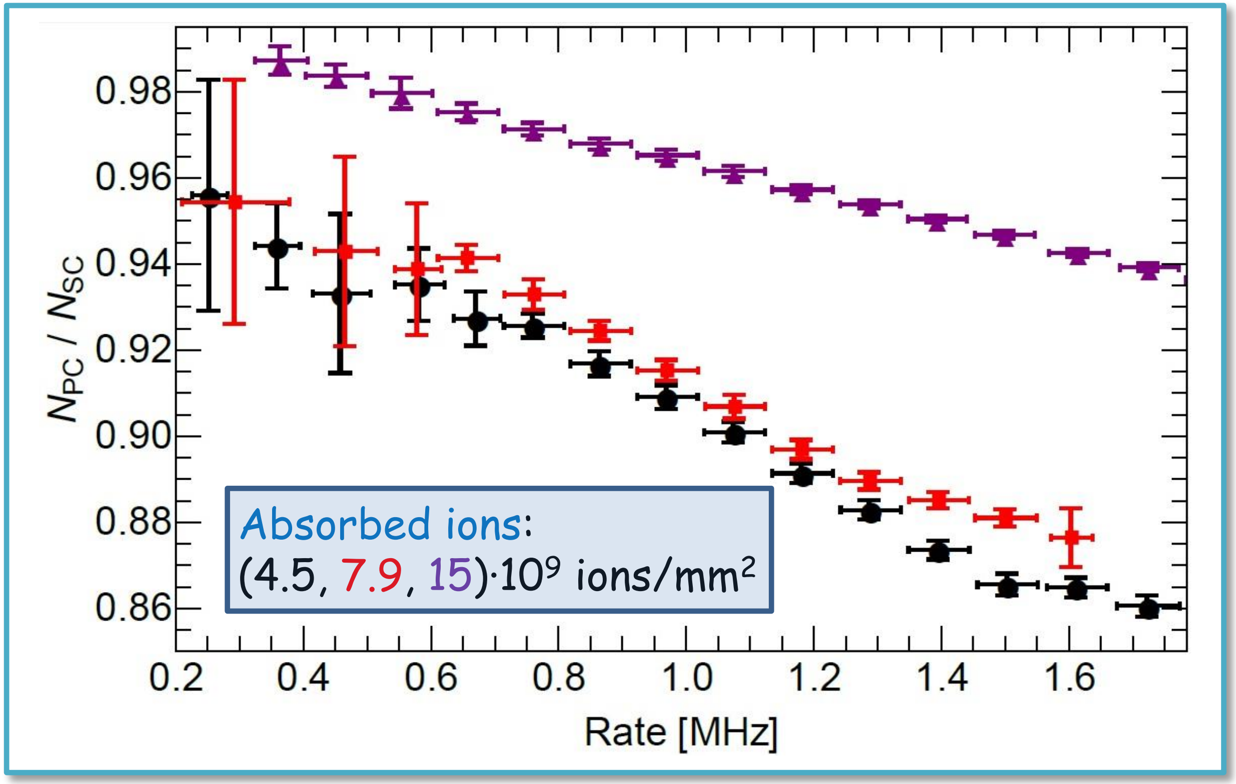
SEM Calibration Factor



The calibration factor was found as linear parameter of a second order polynomial fit [K = (6295 ± 320)·10^{14} ions/A, uncertainty ~5%]

$$N_{ions} = I_{SEM} \cdot K$$

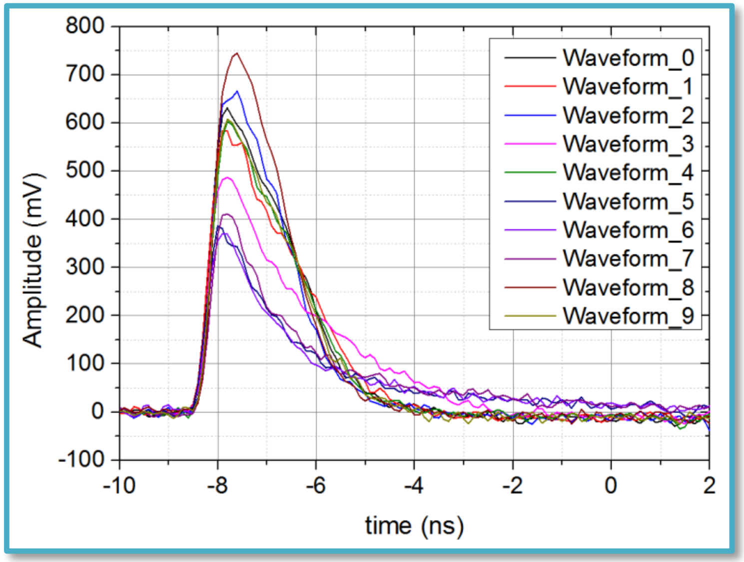
Counting Efficiency Ratio



PC-DD Counting Efficiency [< 700 kHz*]: (94.8 ± 2.5)%

Counting Efficiency Ratio

$$R = \frac{N_{PC-DD}}{N_{SC-DD}}$$



+ Increase with the absorbed ions

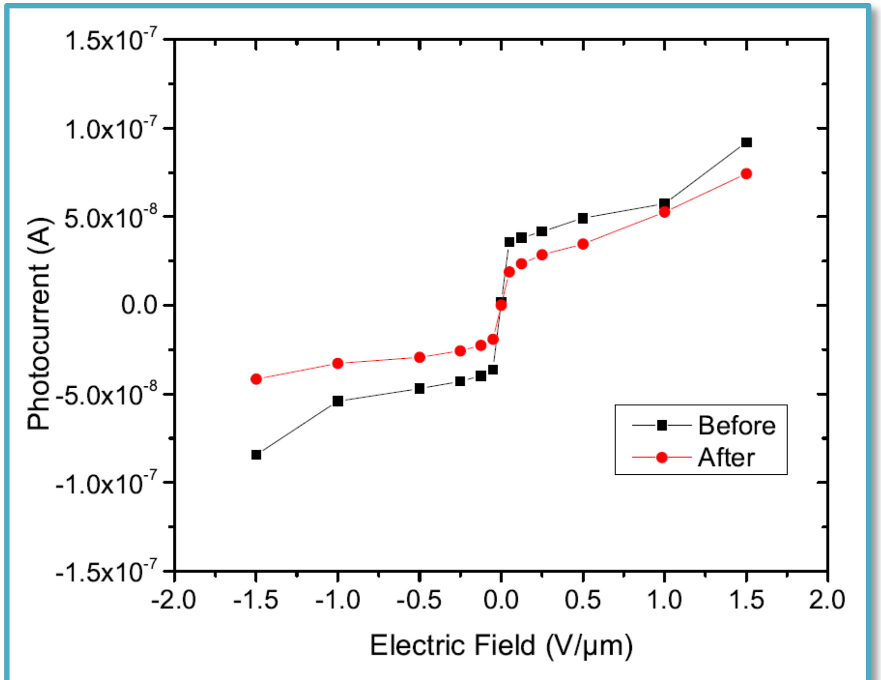
Probably due to an increase of the radiation damage in the scCVD diamond material causing the device to have, with on-going irradiation, a smaller counting efficiency

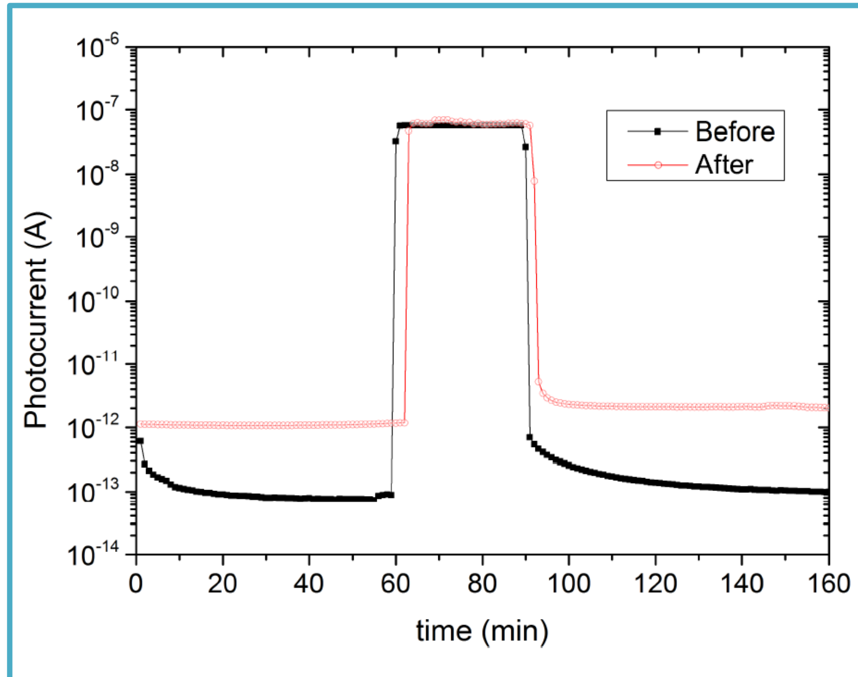
− Decrease with the rate

Linked to the different signal length of the PC-DD as compared to that of the SC-DD (from waveform analysis 14 and 3 ns respectively)

PC-DD has higher probability of being affected by pile-up

X-rays Tests (ii)





- Long term measurements recorded with electric field applied of 1 V/μm
- No remarkable effects on the signal after ^{12}C irradiation

Conclusions

- SC-DD proved to be a very good alternative to the standard absolute reference intensity monitor based on scintillators
- SC-DD can be used to calibrate the SEM within ~5% uncertainty
- PC-DD counting efficiency (94.8 ± 2.5)% for absorbed ions up to $7.9 \cdot 10^9$ ions/mm^2 and beam rate below 700 kHz

The counting efficiency achieved together with the demonstrated radiation hardness* open new perspectives for the use of PC-DDs as particle intensity monitor.

Integration and technical design of PC-DDs within the particle detector combination (PDC) along the beam line in the Super-FRS@FAIR is under discussion.

Detailed information regarding this research work are included in the PhD thesis of S. Schlemme (2019) which can be found here: https://tuprints.ulb.tu-darmstadt.de/8843/

*S. Schlemme et al., "*Long-term exposure of a polycrystalline diamond detector irradiated by 62 MeV/nucleon carbon beams*", Diamond and Related Materials, Volume 99, 2019