33rd RD50 Workshop, CERN, 26-28 November 2018

Radiation damage tests on silicon pad diodes with heavy ions at CERN IRRAD & CHARM facilities

Isidre Mateu, Federico Ravotti, Giuseppe Pezzullo, Michael Moll

CERN, Geneva, Switzerland

CERN | IRRAD Proton Facility

AIDA 2020

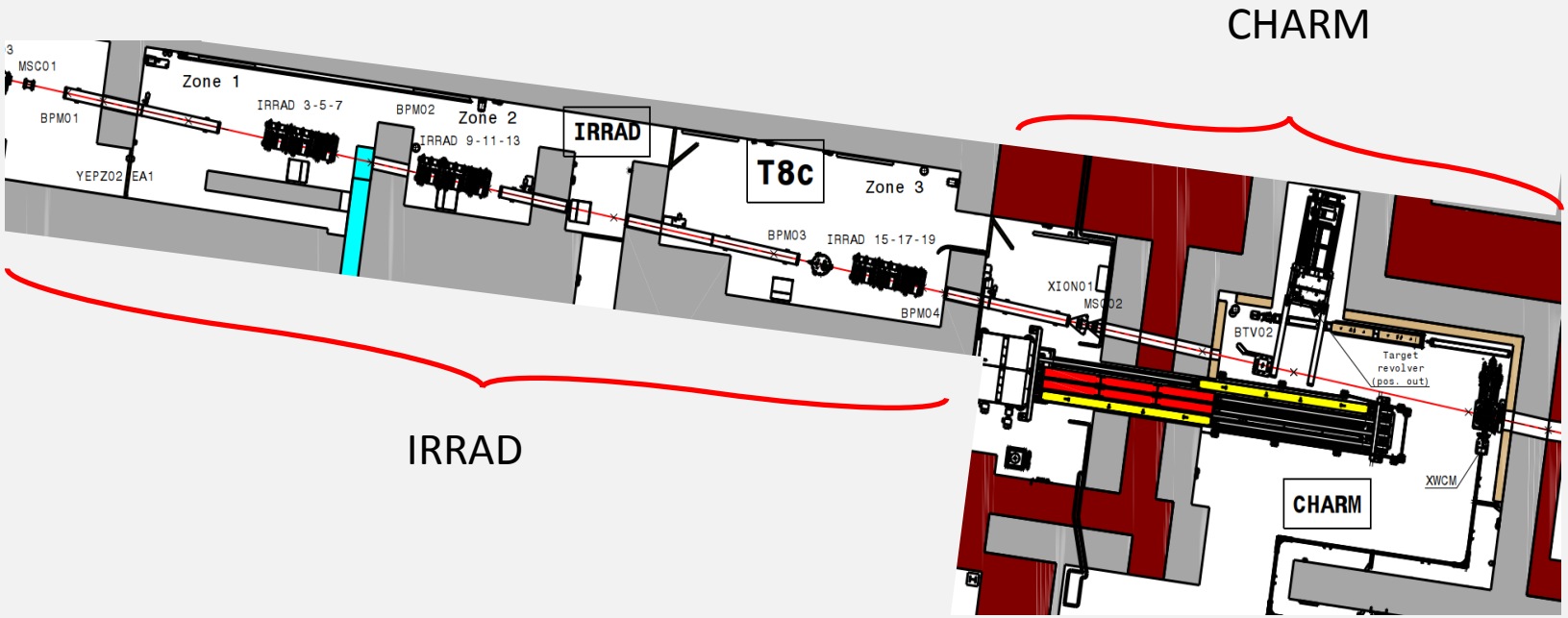
Outline

1. Heavy ions at CERN PS East Area.
    1. Motivation.
    2. 2017 and 2018 ion beams.
    3. Beam instrumentation.
2. NIEL study on silicon pad detectors.
    1. Introduction.
    2. Experimental conditions.
    3. Preliminary results.

1.Heavy ions at CERN PS East Area

Motivation

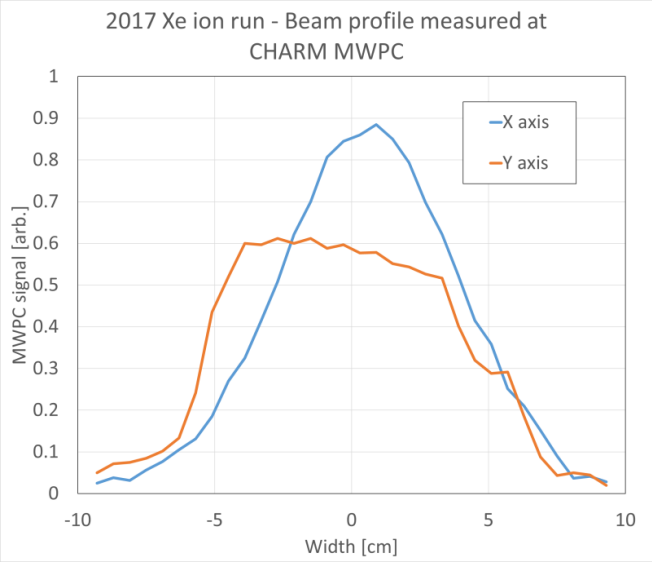
- Radiation Hardness tests of Space Electronics Components (CHARM).
- High energy ions (few GeV/n range)
  - Representative of the Galactic Cosmic Ray spectrum (peak fluxes at ~1 GeV/n).
  - Highly penetrating.
  - ~Constant Linear energy Transfer over the device under test volume.
- Characterize and propose IRRAD as a test area for EP heavy ion experiments (ALICE, NA61, etc.)
- 1st run in 12/2017 (Xenon ions) and 2nd run currently ongoing (Lead ions).

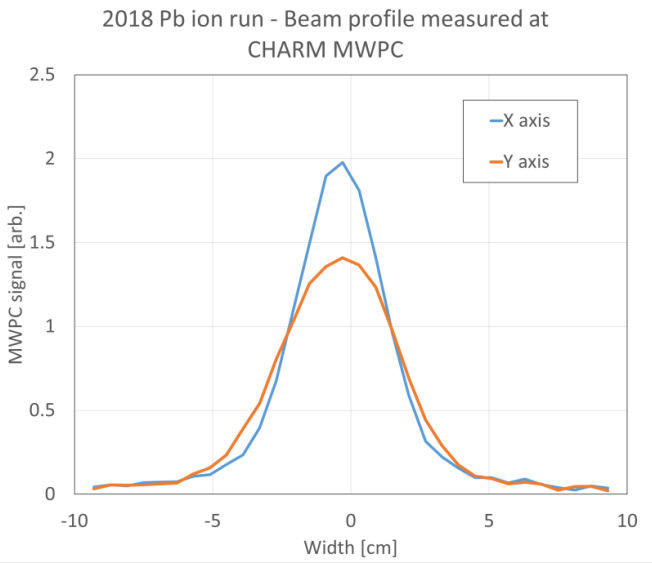


2017 and 2018 ion beams

	2017	2018
Element	Xenon (Xe)	Lead (Pb)
Charge state in the PS accelerator	39+	54+
Charge state after extraction*	54	82
Energy per nucleon	6.3 GeV/n	5.9 GeV/n
#nucleons	130	208
Ion energy	820 GeV	1222 GeV
Spill duration	~300 ms	
Ions/spill**	~2.8e8	1.3e9

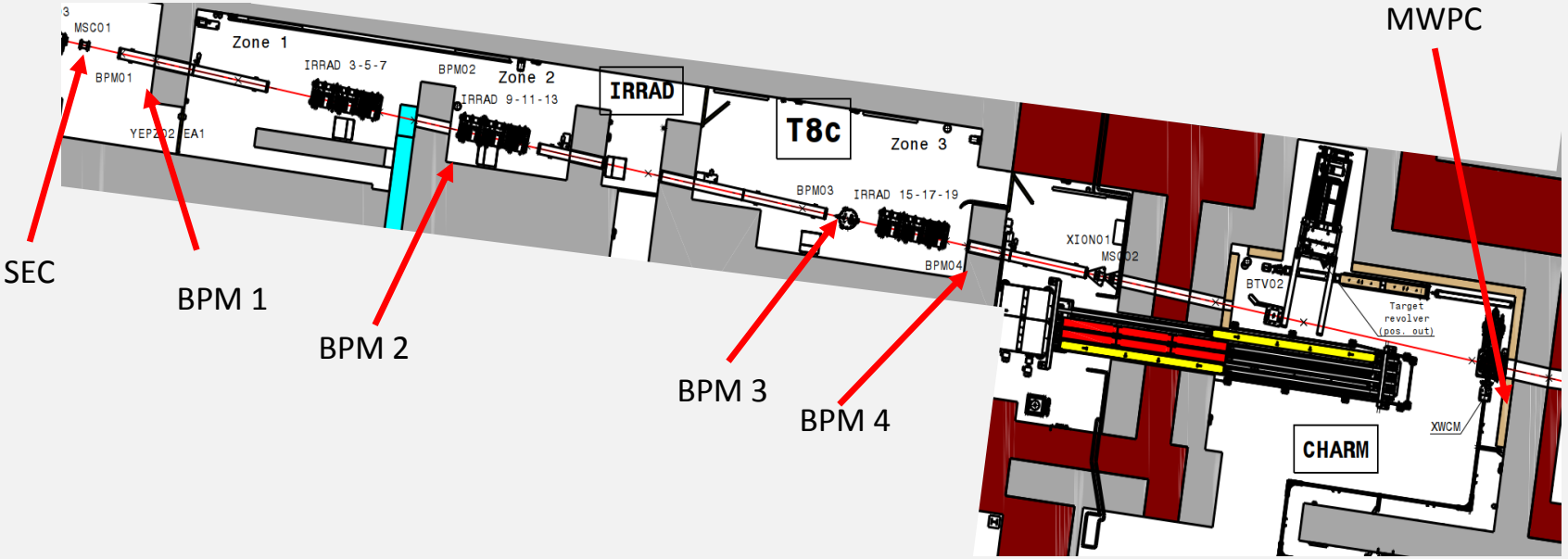
**ions are assumed to become fully stripped during the extraction.*
***From beam instrumentation calibration (see next slide)*





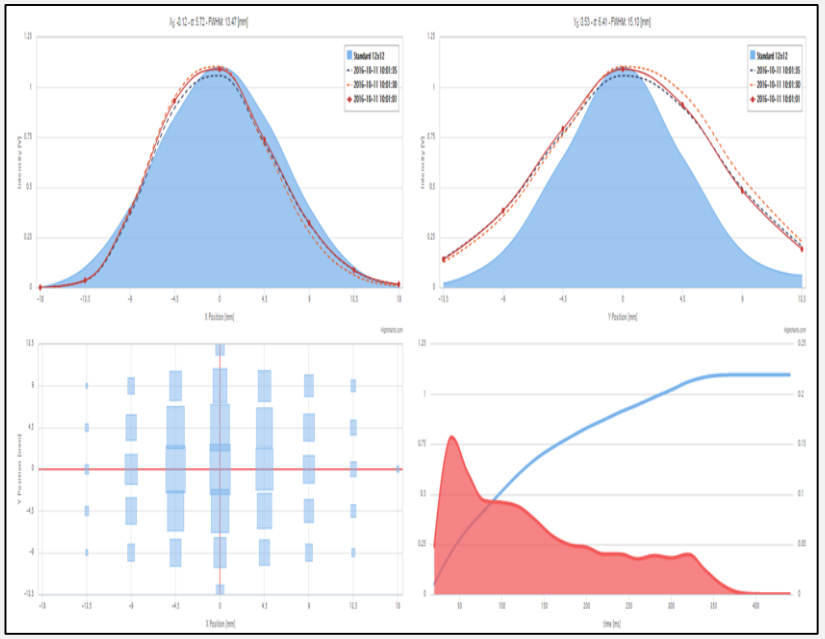
Beam instrumentation

- The IRRAD beam intensity is usually measured with a Secondary Emission Chamber (SEC), upstream of the facility.
  - Calibrated for ions against a Beam Current Transformer (BCT) measurement in a fast extraction run (~600 ns spills).
  - **Assumption:** the SEC response is maintained from fast to slow extraction.
- Beam profile is monitored using the IRRAD and CHARM instrumentation, normally dedicated to the proton beam.
  - Beam Profile Monitors (BPM) in IRRAD.
  - X-Y Multi Wire Proportional Chamber (MWPC) in CHARM.

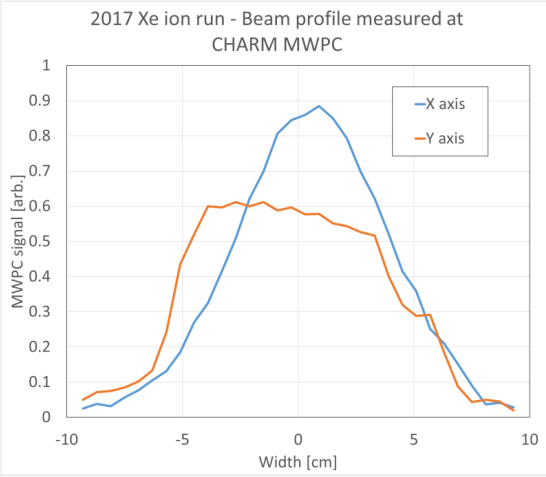


Beam instrumentation

- The **BPM** are patterned copper foils working on the same physical principle of the SEC.
  - Patterned with 40 pads of equal size and 4.5 mm pitch (x and y).
  - Covering an area of 31 x 22 mm^2.
  - Linear response up to the highest intensities with the typical proton beam in IRRAD.



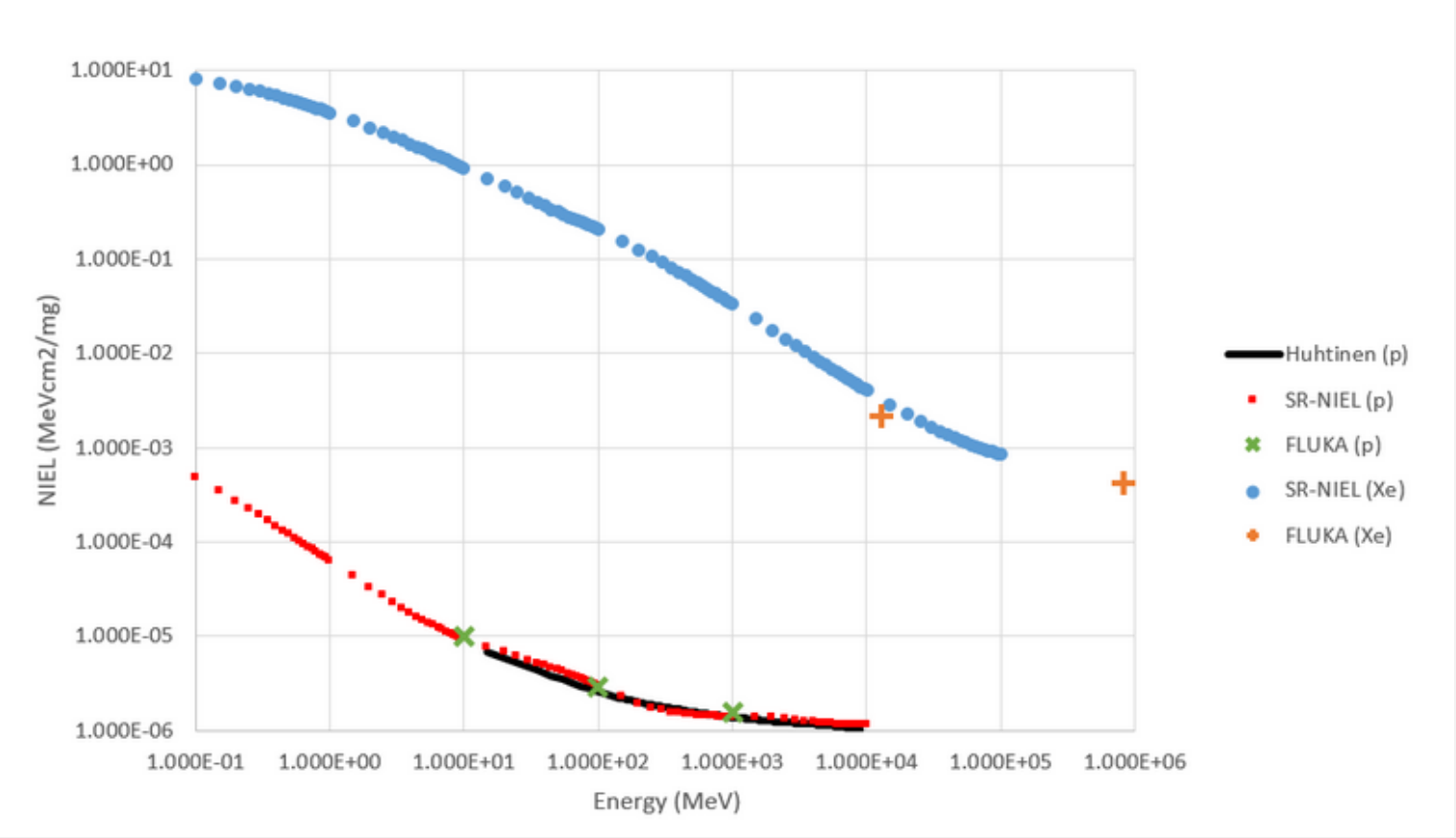
- **MWPC:**
  - 32 wires in each axis with 6 mm pitch.
  - 18.6 x 18.6 cm^2 coverage.
  - Expected to saturate with the ion beam.



2.NIEL study on silicon pad detectors

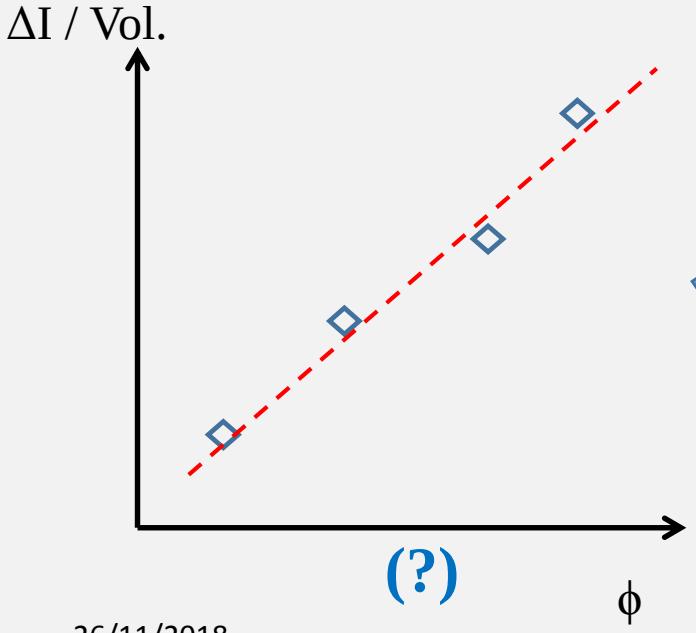
Introduction

- No previous work on NIEL measurements for heavy ions in the GeV/n energy range.
- Only analytical methods and simulations are available.



Introduction

- Attempt to use the heavy ion beams in IRRAD/CHARM to determine their hardness factors by measuring the current related damage factor α.
- Several pad diodes irradiated in different time steps and increase in leakage current measured after 80 min@60° C annealing step.



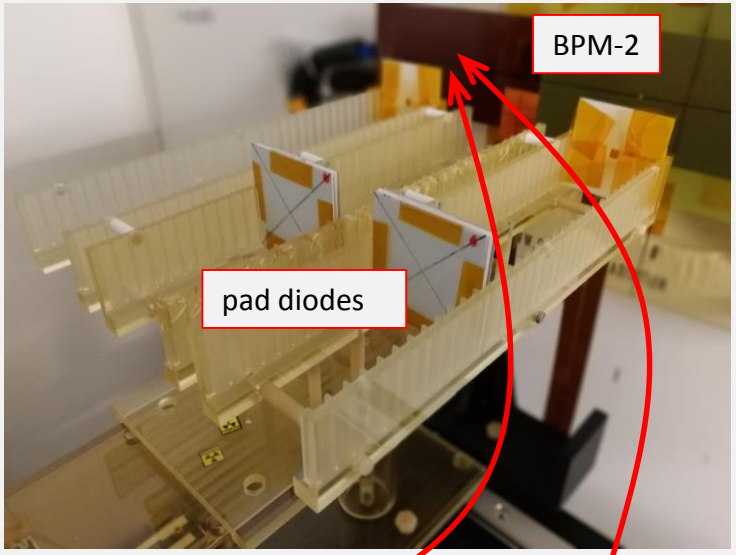
Main challenge: determining the fluence!
(no activation measured on aluminium foils…)

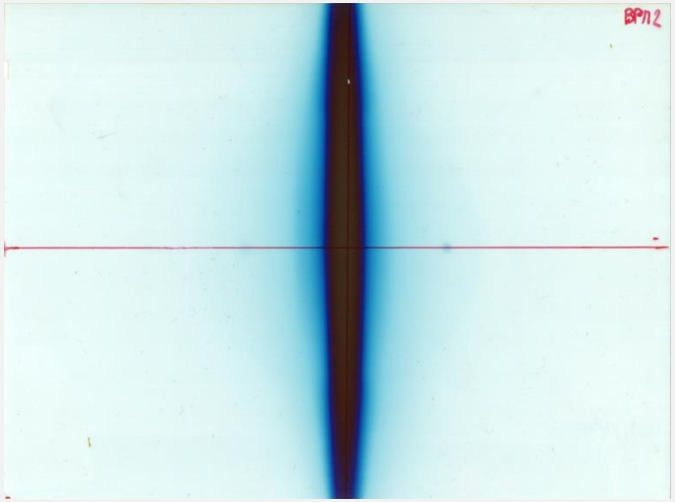
Estimation based on the SEC calibration and closest beam profile measurement

Experimental conditions

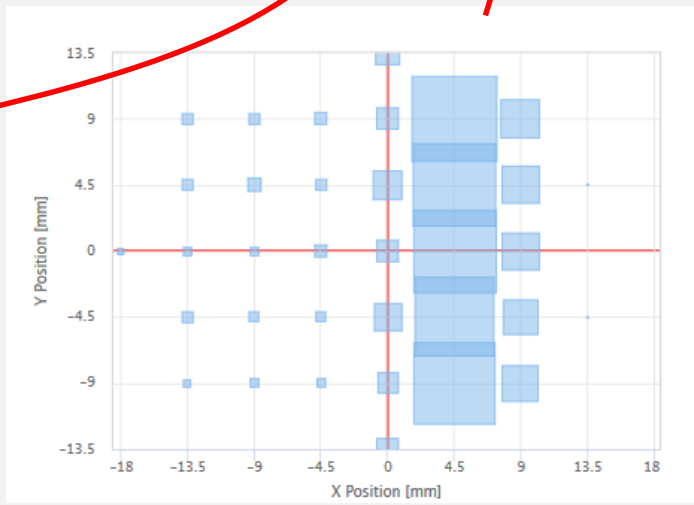
2017

- Experiment performed in IRRAD, close to BPM-2.
- 2.5x2.5 mm^2 active area diodes.
- Uncertainties in determining the fluence:
  - Close to beam focus on X axis (high fluence gradient, sensitive to misalignments).
  - Beam not fully contained in the BPM In the Y axis.





Gafchromic film installed on the BPM-2

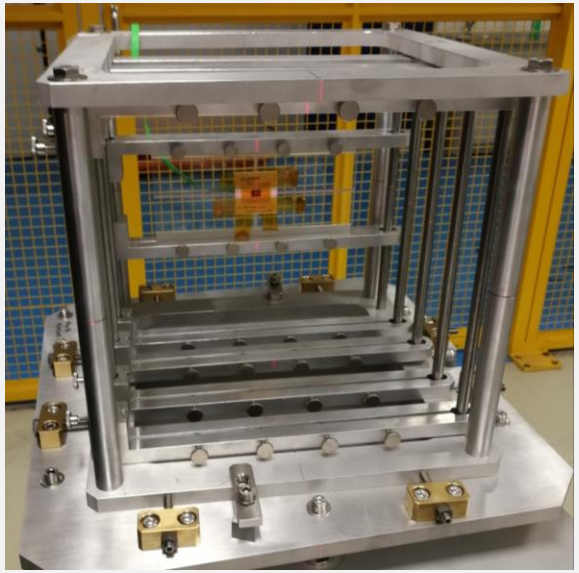


Screenshot of the BPM-2 web display.

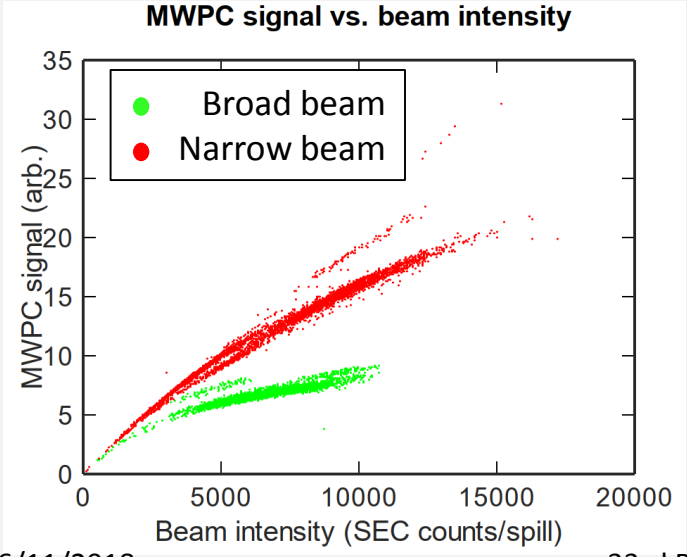
Experimental conditions

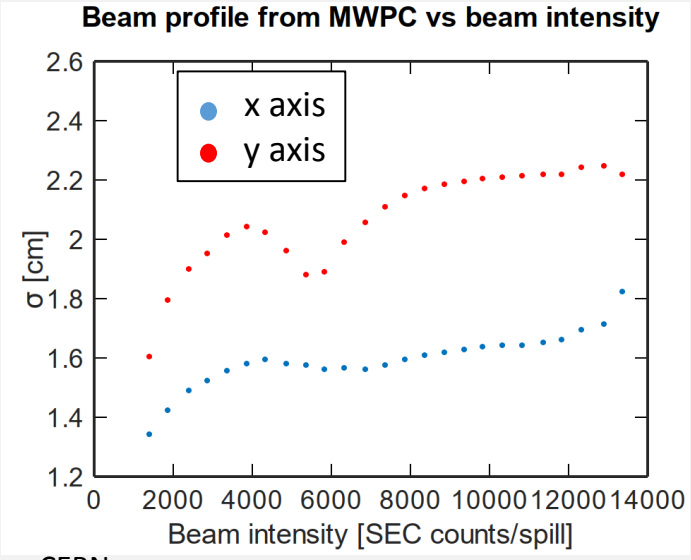
2018

- Experiment in CHARM to have a more uniform beam profile.
- 5x5 mm^2 active area diodes.
- Uncertainties in determining the fluence:
  - Non linear response of the MWPC induces a distortion of the measured profile.
  - Very different responses for events with similar beam intensity (under investigation).



Samples mounted on the CHARM conveyor



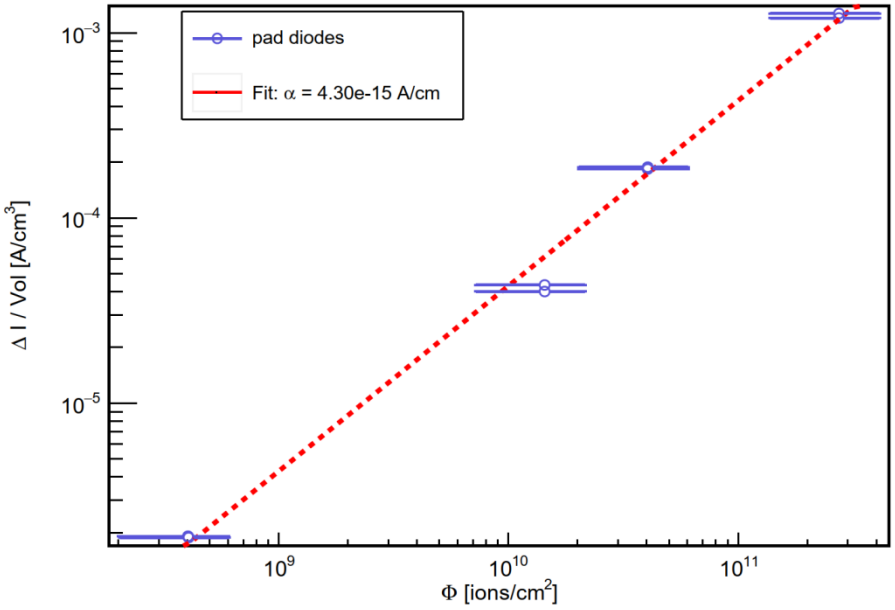


Results

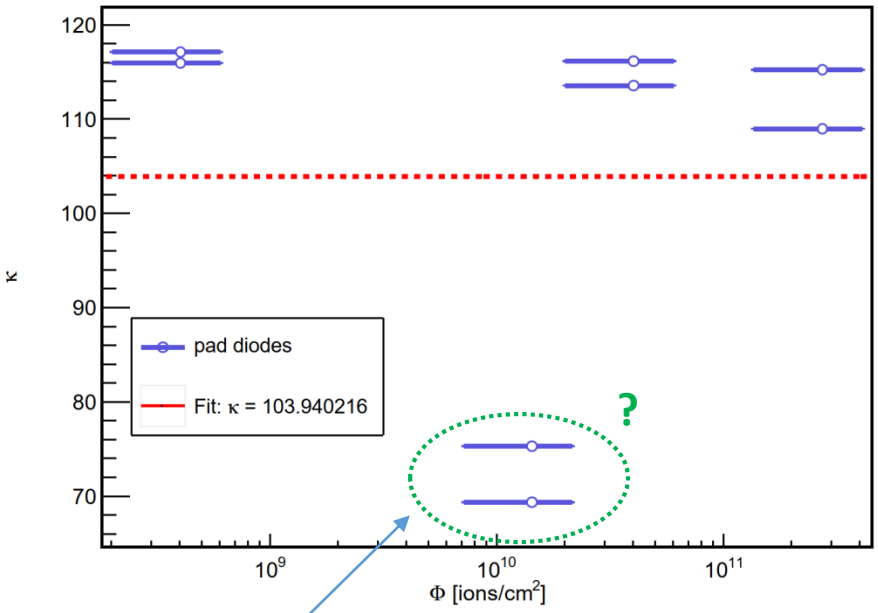
2017 - Xenon

PRELIMINARY

Leakage current scaling with fluence, 80 min@60° ann. time



Hardness factor vs. fluence, 80 min@60° ann. time



Hardness factor measured ~115 (excluding outlier)

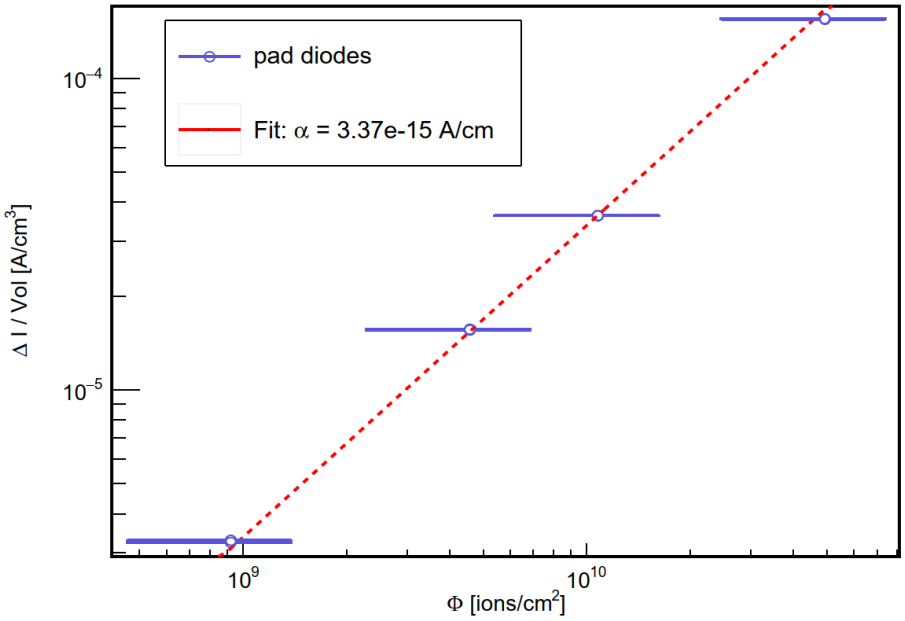
Values from FLUKA simulation and SR-NIEL are around 207!

Results

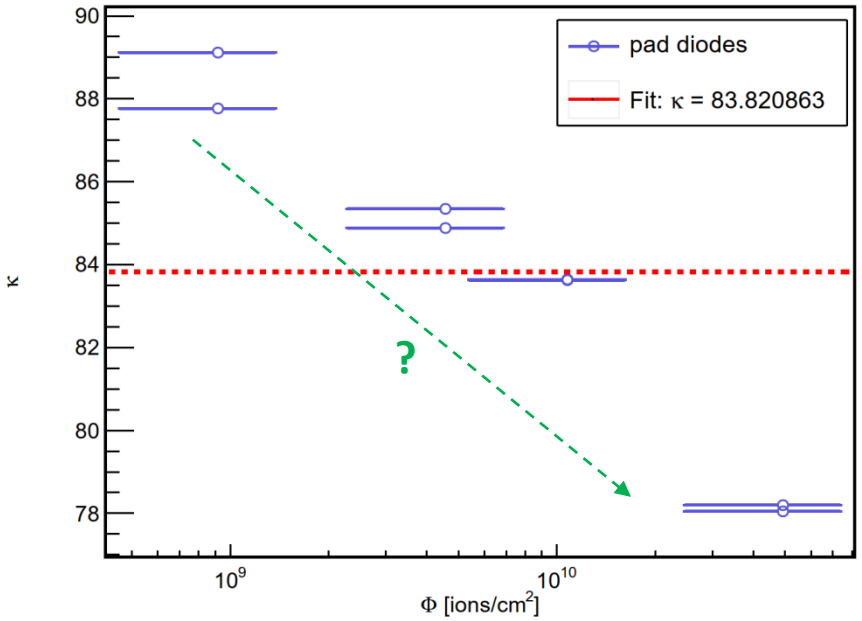
2018 - Lead

PRELIMINARY

Leakage current scaling with fluence, 80 min@60° ann. time



Hardness factor vs. fluence, 80 min@60° ann. time



Hardness factor measured ~84

Values from FLUKA simulation and SR-NIEL are around 400!

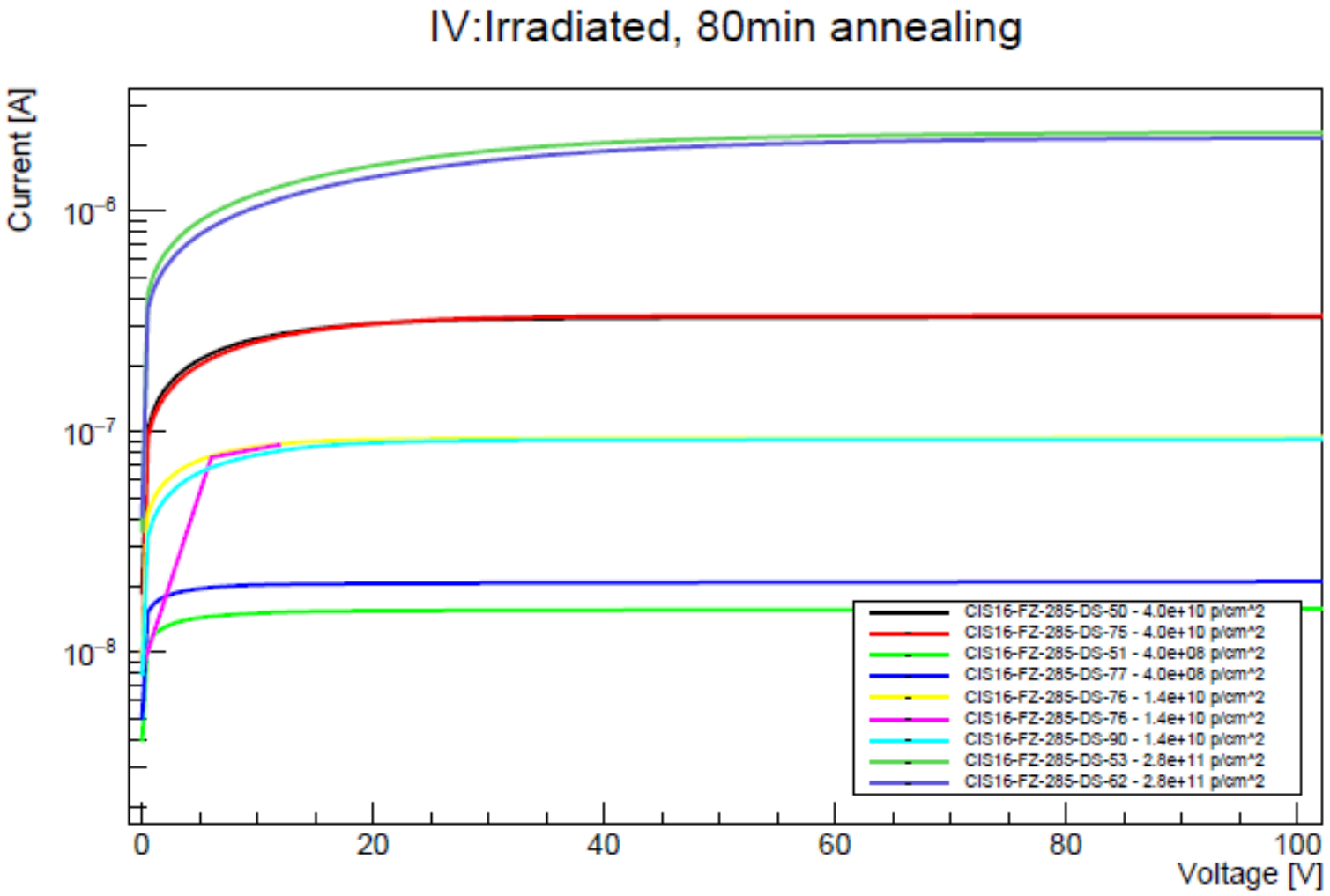
Summary & Outlook

- Heavy ion runs performed in IRRAD/CHARM in 2017/18.
  - Xe 6.3 GeV/n and Pb 5.9 GeV/n.
- Experiment on NIEL in silicon performed.
  - Too many uncertainties to reliably determine the ion fluence (Mainly SEC calibration and beam profile).
  - Preliminary analysis show that measured and simulated (FLUKA) NIEL values differ largely.
  - Ion Beam dosimetry is a challenge for both the accelerator and the facility (lack of methodologies and experience).
- Outlook:
  - Get a better understanding of the beam instrumentation (verify assumptions made in present calculations).
  - Improve the data analysis for the ion fluence estimation (combine MWPC and BPM data?).
  - TSC and DLTS measurements on irradiated diodes.
- Most likely further ion runs after LS2.
  - **Potential users in the RD50 community?**
  - Potentially prepare a further experiment with improved beam diagnostics/dosimetry.

Spares

Results

2017 – I-V curves (Xenon)



Results

2018 – I-V curves (Lead)