Development of the proton beam monitor based on the thin diamond crystal for the COMET Experiment

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I. COMET Experiment

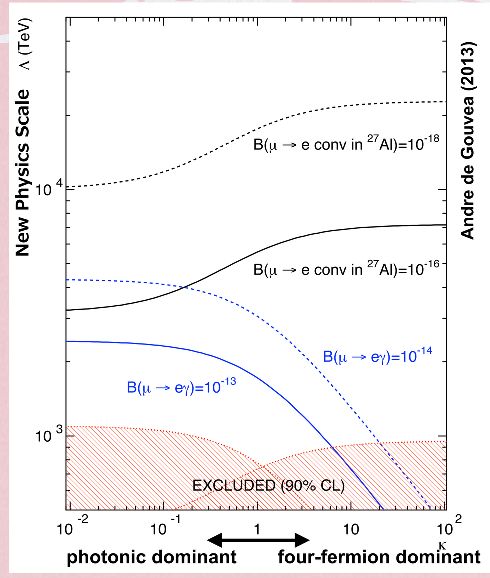
Introduction

- The COMET Experiment aims to search for the muon to electron (μ-e) conversion in nuclei with the sensitivity below 10^{-16}
- *BR*(μN→eN) is negligible in SM+ν-oscillation ($O(10^{-50})$)

↔ Many new physics predict sizable *BR*(μN→eN), $O(10^{-15})$

- μ-e conversion = clear evidence of new physycs
- The current upper limit is set to 7×10^{-13} (SINDRUM-II)

➡ *Very close to the new physics !*



Signal and Backgrounds

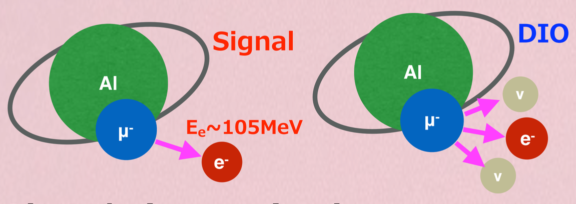
- Signal: *105MeV single electron*
- Intrinsic BG: Decay In Orbit(DIO)

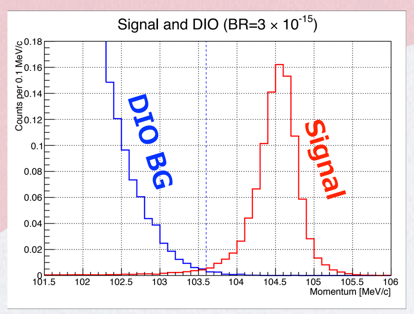
Broad spectrum <105MeV/c → σ_p<200keV/c is required

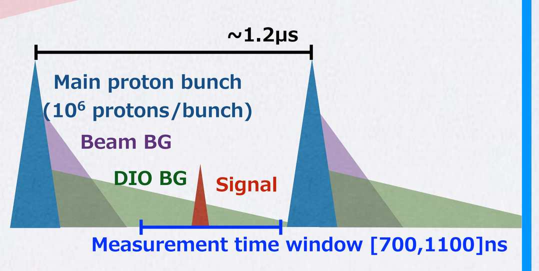
- Beam origin BG: μ/π decays in-flight, etc.

➡Bunched beam + Off-time measurement

➡Long μ/π transportation

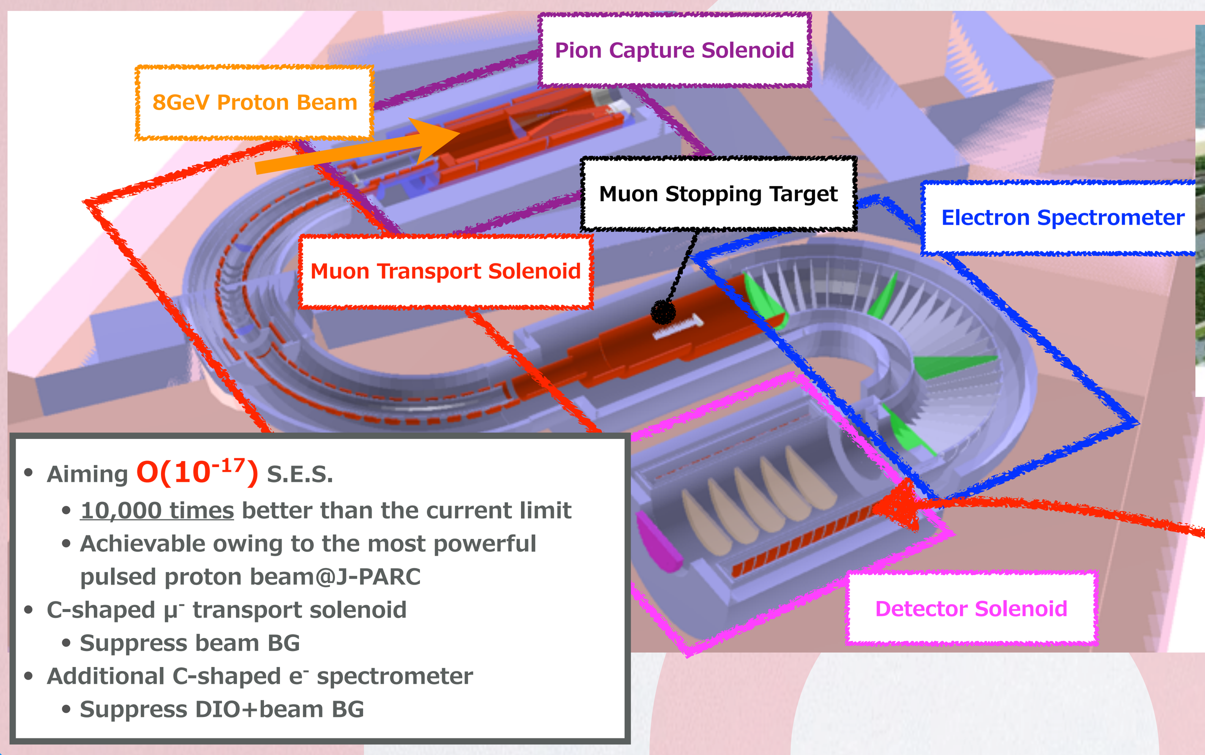


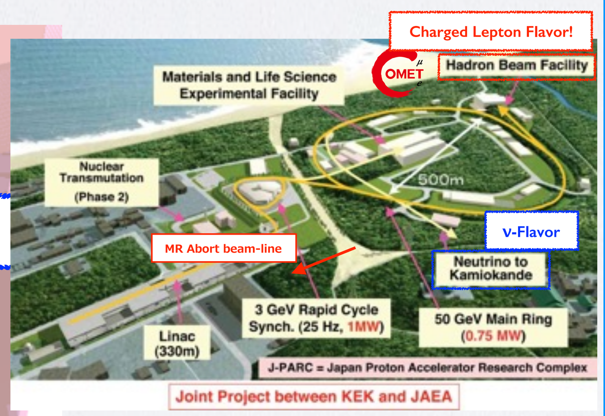


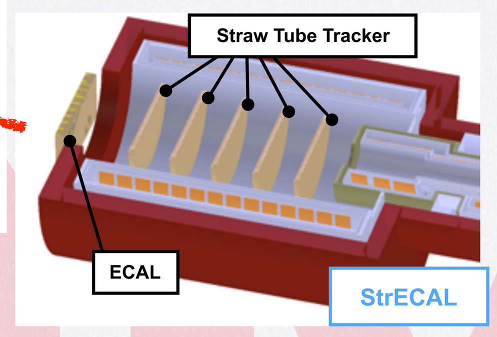


COMET Experiment

will be conducted @J-PARC as shown below





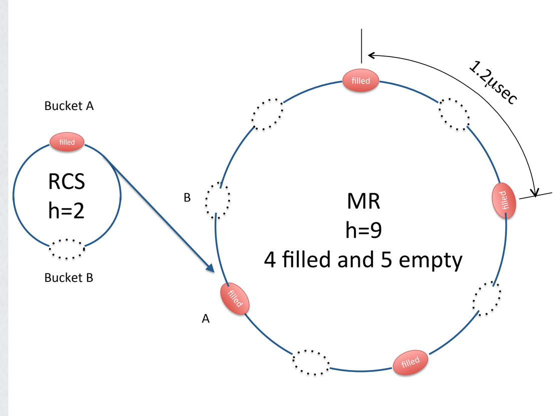


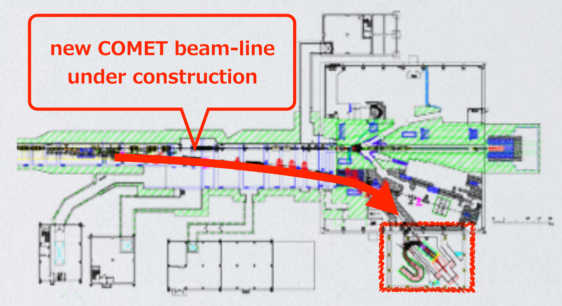
II. J-PARC Proton Beam and Extinction for COMET

Proton Beam for COMET @J-PARC

COMET requires dedicated "bunched slow extraction"(BSX*)

- Energy 8GeV → Power 3.2/54kW for Phase-I/PhaseII
- 1.2μs bunched beam by filling only one bucket in RCS
- New beam line is under construction to deliver the proton beam from MR to COMET Experiment hall @HD hall





Extinction

"Extinction" factor:

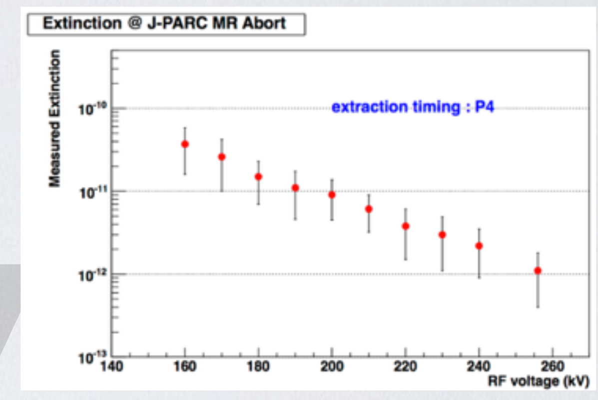
$\mathcal{R}_{ext.}$= (#of residual protons)/(Total# of protons in a bunch)), *should be lower than* 10^{-10}

➡ $<10^{-10}$ $R_{ext.}$ is already obtained w/ FX beam

➡ Measurement @HD w/ BSX beam was performed recently

In any case, "direct" extinction monitor is essential for COMET to strongly eliminate critical background due to such residual protons!

*NSX: Normal Slow Extraction (continuous beam), FX: Fast Extraction (pulse)



III. Diamond based Proton Monitor

Diamond based Proton Monitor

A diamond detector was chosen as a COMET online extinction monitor:

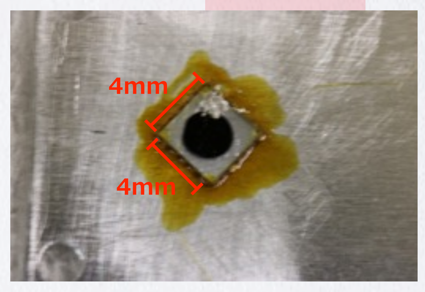
1. High radiation tolerance up to 10^{16} n_{eq}/cm^2 and O(10)MGy
2. Capable to detect a proton between bunches with $O(10^6)$ of protons

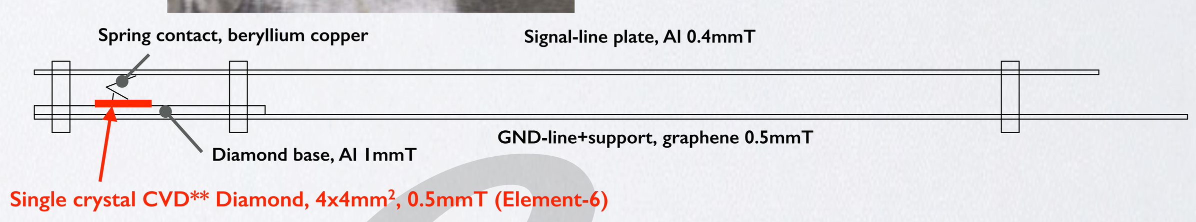
The detector will consist of O(1-10) diamonds, metal contacts and base materials to cover 2σ beam region (~20x20mm²). $O(10^4)$ *e-h* pairs are expected from one proton MIP.

Prototype Detector I

The 1st prototype for direct proton measurement was developed in 2016

- Ultra vacuum compatible → $O(10^{-6})$Pa inside the beam pipe of J-PARC MR
- Low residual radioactivity → 10μSv/h after the beam irradiation for safety point of view
- Small&discrete signals were observed in SX beam operation mode, likely due to few protons



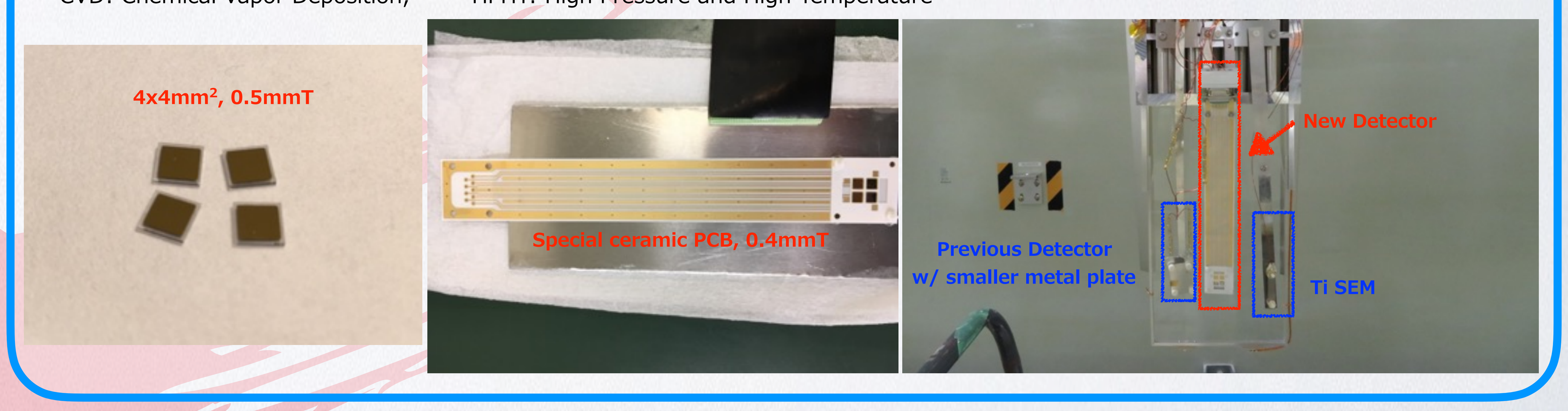


Prototype Detector II

New prototype was recently developed to confirm the few protons observation

- Wider coverage, more uniform metal contacts (Pt/Mo/Au)
- A 400μm thin ceramic PCB for better signal conductivity
- Two different diamonds for performance comparison (E-6 CVD, New Diamond Tech. HPTH***)
- Three features of prototype-I is kept as well

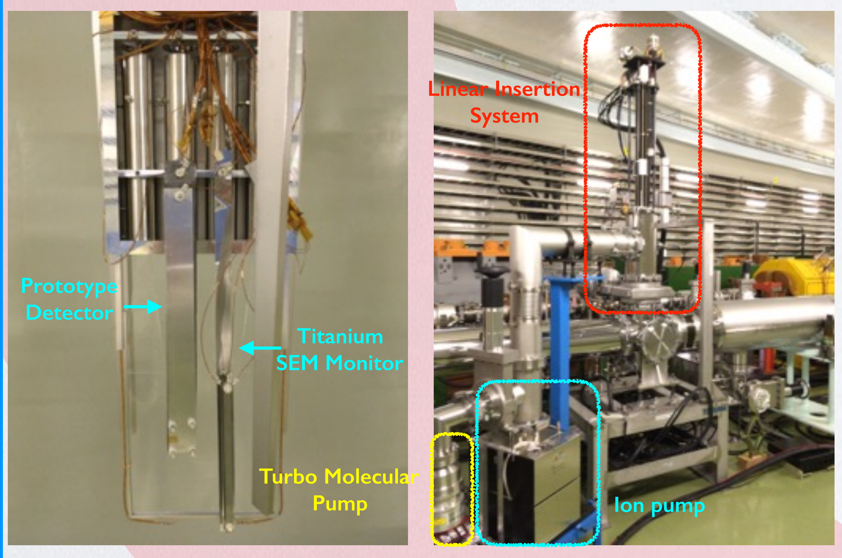
** CVD: Chemical Vapor Deposition, *** HPHT: High Pressure and High Temperature

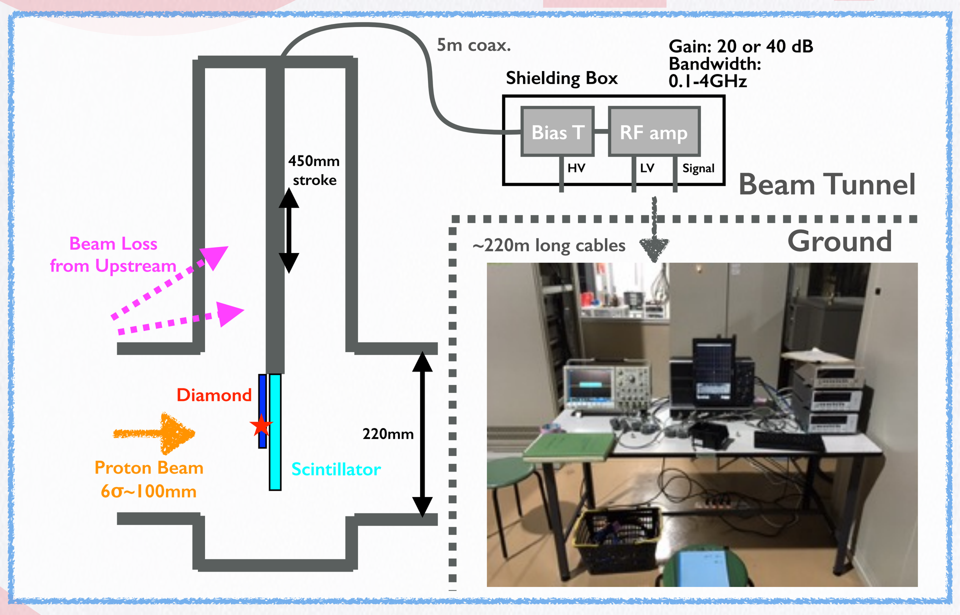


IV. Direct Proton Measurements

Direct proton measurements performed @J-PARC MR abort-line until now

Experimental Setup





High intensity test

To validate the radiation tolerance of the detector, the direct proton measurement was done

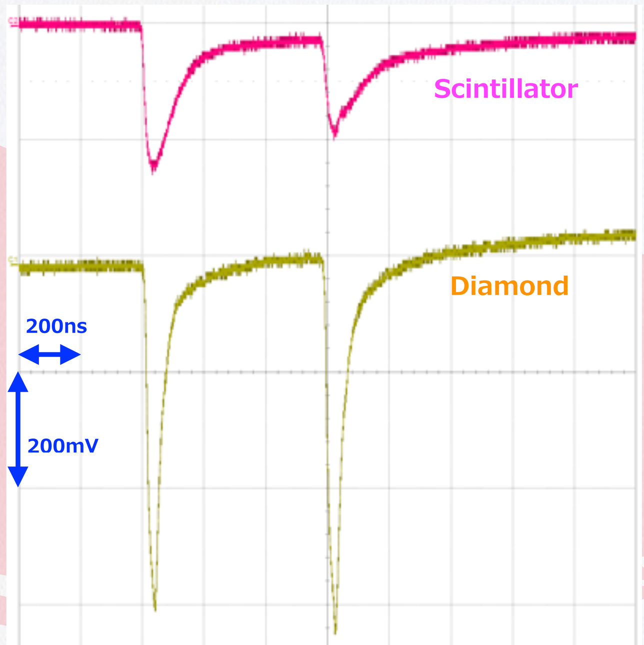
➡Observe clear signal correlated with a scintillator's signal

➡The pulse width is consistent with that of the proton beam (~30ns FWHM)

➡Falling time is fast enough to measure the small #of protons between bunches.

The continuos proton beam irradiation was tested up to $O(10^{14})$ protons/cm² of total protons

➡ No critical damage



Low intensity test

During NSX beam operation, the counting of the small #of protons was demonstrated. *NOTE*: signal size from one proton is estimated to be 0.1-0.3mV

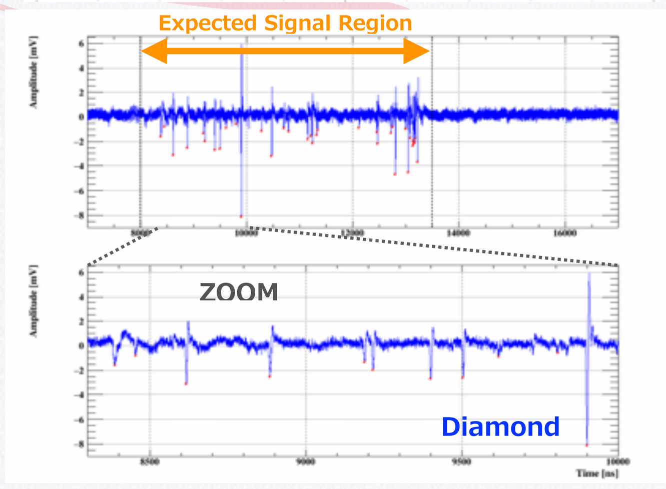
- Use high pass filter (>60MHz)

➡Sharp pulses only in the expected signal window

➡Pulse heights are consistent with the expectation value

➡ Signals from few protons?

Difficult to confirm due to bad S/N though…

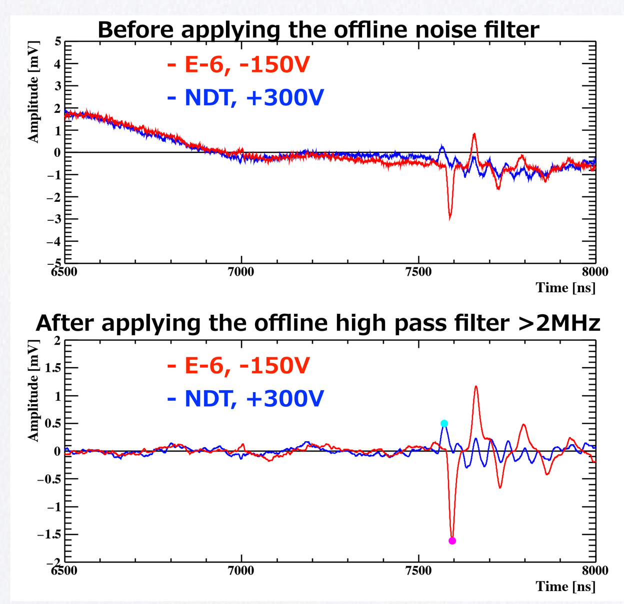


The new measurement w/ Prototype II

- High pass filer is unnecessary thanks to the better S/N
- Installation was done in January 2018
- Beam data was already taken w/ SX beam
- Offline noise reduction is developed and well performed
  - Excellent noise level, ~0.15mV is achieved
  - However, not enough to distinguish a single proton yet
- Clear signals are observed, but reflections appear

➡Need to solve the impedance mis-matching

- E-6 shows larger and sharper signal than NDT



V. Summary and Prospects

Summary

- Proton beam monitor is essential for COMET to measure the extinction on-time
- Diamond detector will be installed to as an online extinction monitor
- The measurement of the high intensity pulsed proton beam was done successfully
  - No clear deterioration has been observed up to $O(10^{14})$ protons/cm²
- Small proton detection was performed
  - Discrete pulses due to few protons are observed
- New prototype has been developed and installed to confirm above result
- Data taking was done w/ SX beam → S/N is improved, but still not enough
- E-6 shows larger pulse, similar noise level for both diamonds (0.15mV in RMS)

Prospects

- Front-end electronics will be improved to get better S/N
- Additional data will be taken in the next SX period to get more statistics
- Further irradiation has to be done soon

VI. Acknowledgement

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