Diamond as potential CryoBLM for the LHC

All results are preliminary

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acknowledgments

Christoph Kurfuerst for
CryoBLM Team
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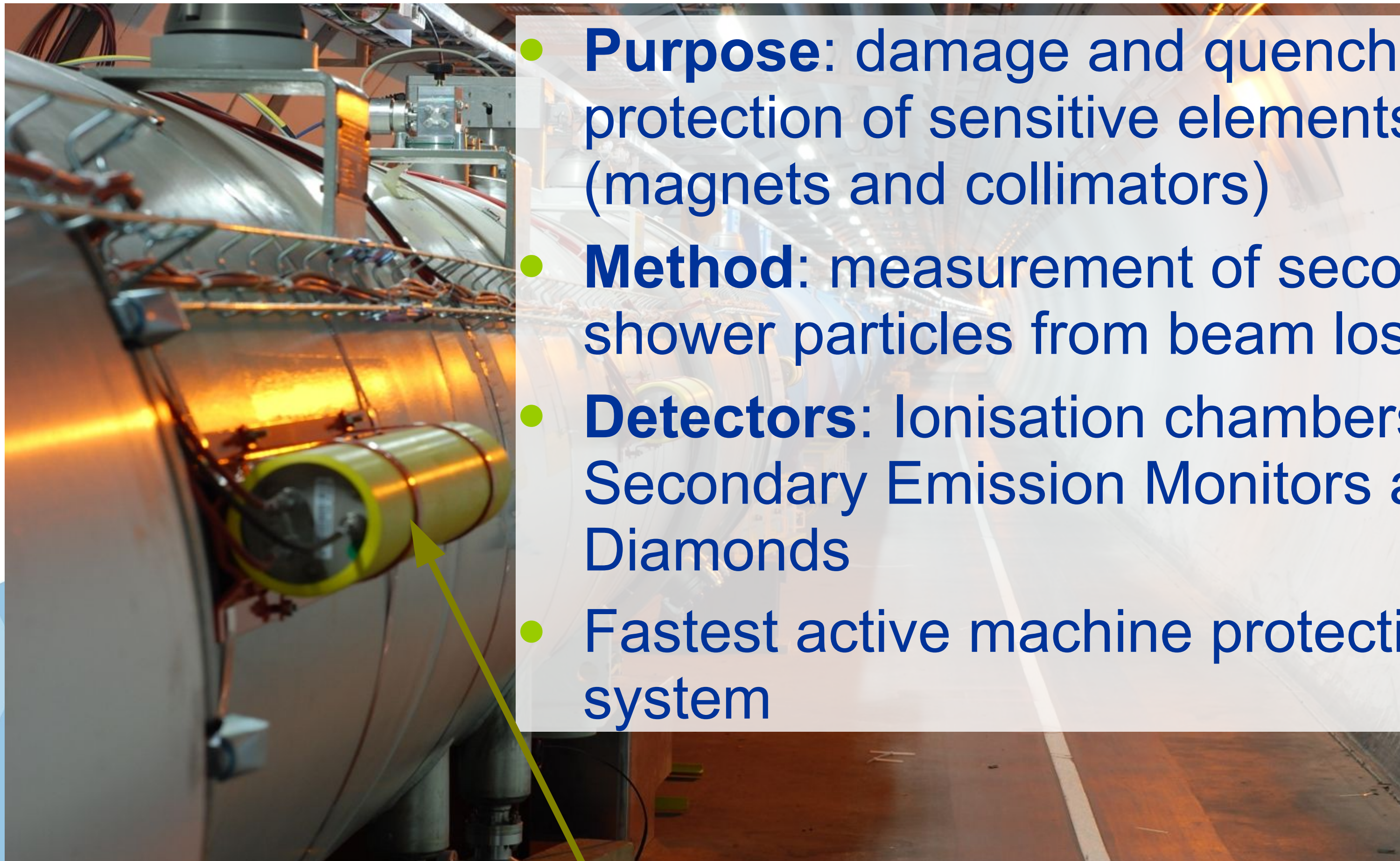
Outline

- Motivation
- Room temperature irradiation
  - First results
- Cold Irradiation
- LHC detectors installation
- Conclusions and outlook

LHC Beam Loss Monitoring

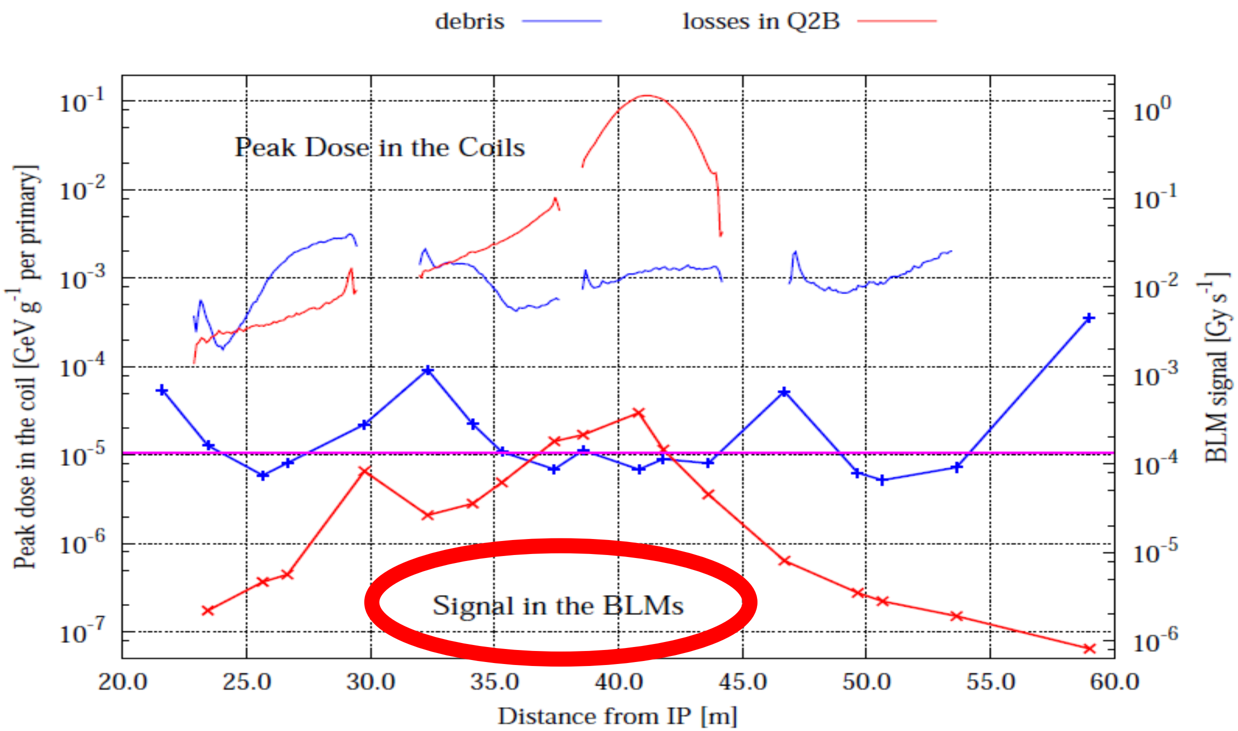
- **Purpose**: damage and quench protection of sensitive elements (magnets and collimators)
- **Method**: measurement of secondary shower particles from beam losses
- **Detectors**: Ionisation chambers, Secondary Emission Monitors and Diamonds
- Fastest active machine protection system



Limit close to interaction regions

Problem: in triplet magnets signal from debris with similar height as simulated beam losses in steady state case

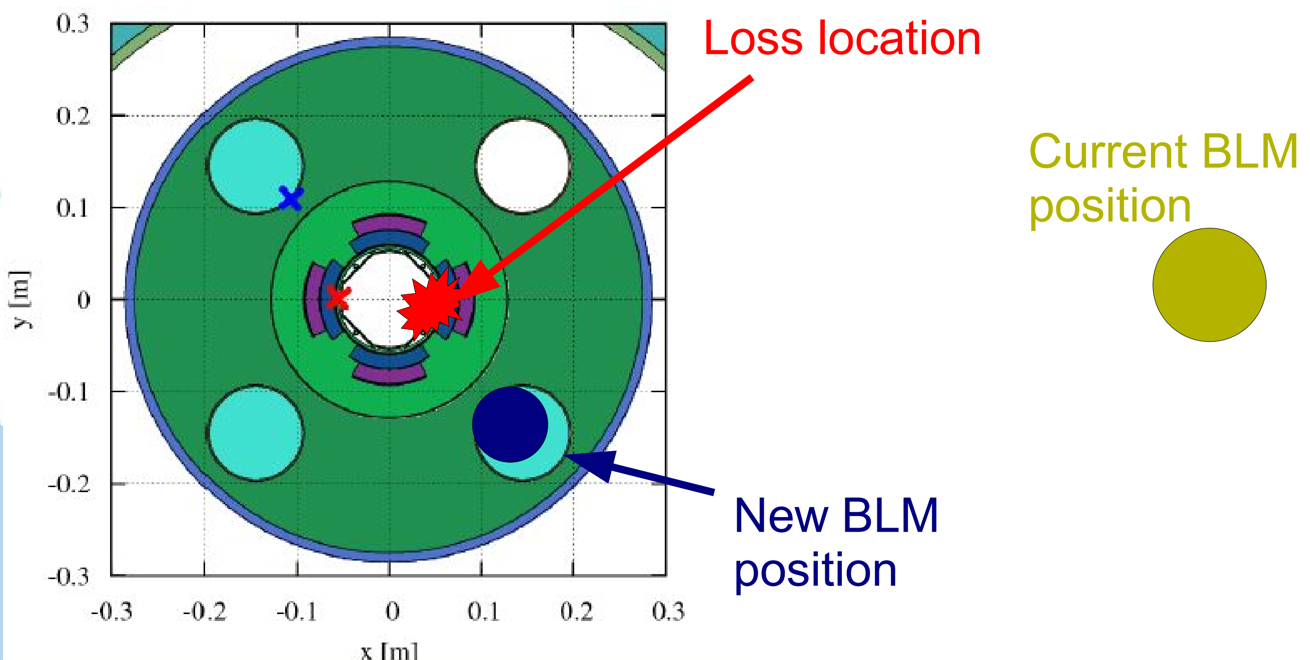
7 TeV, nominal luminosity



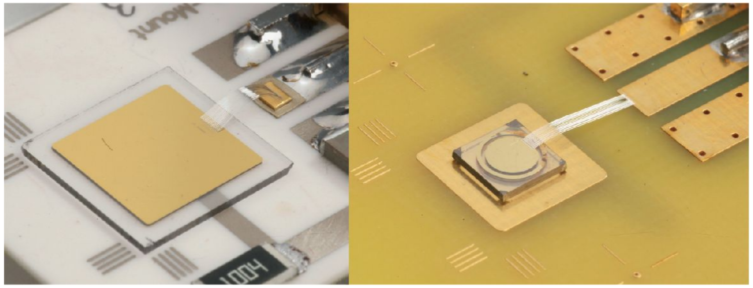
Courtesy Alessio Mereghetti

Cryogenic BLM as solution

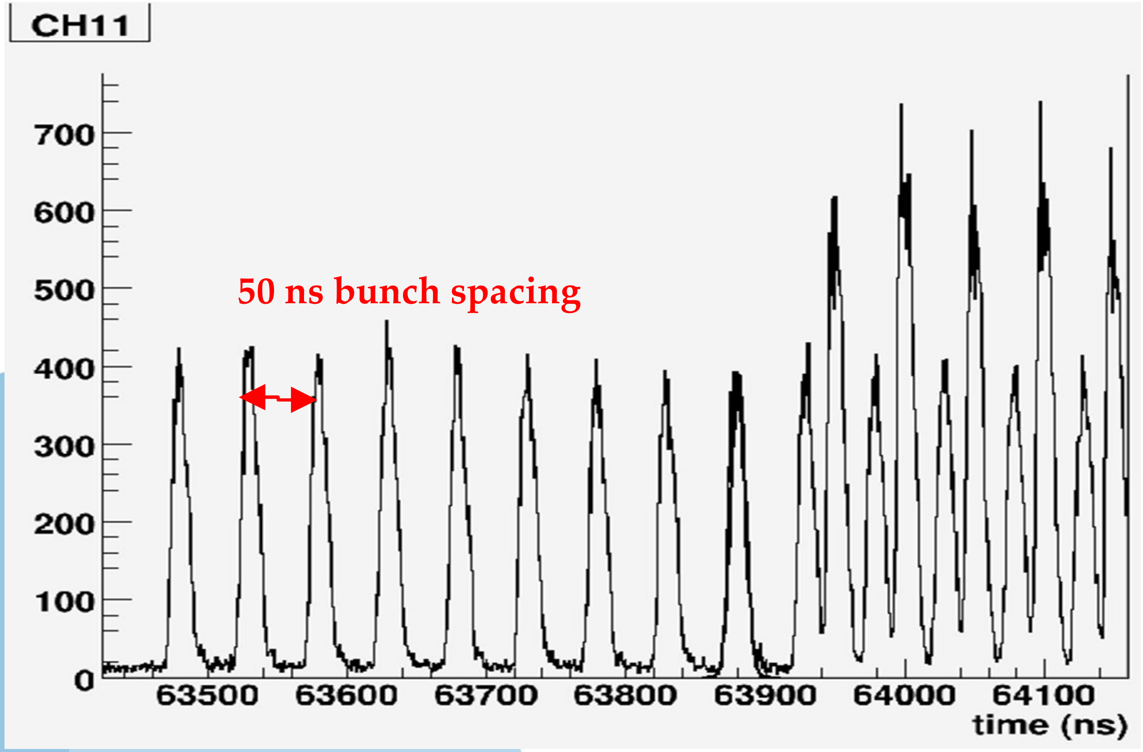
- Future BLMs placed closer to:
  - where losses happen and
  - the element needing protection (so inside cold mass of the magnet, 1.9 K)
- Measured dose then better corresponds to dose inside the coil



Diamond



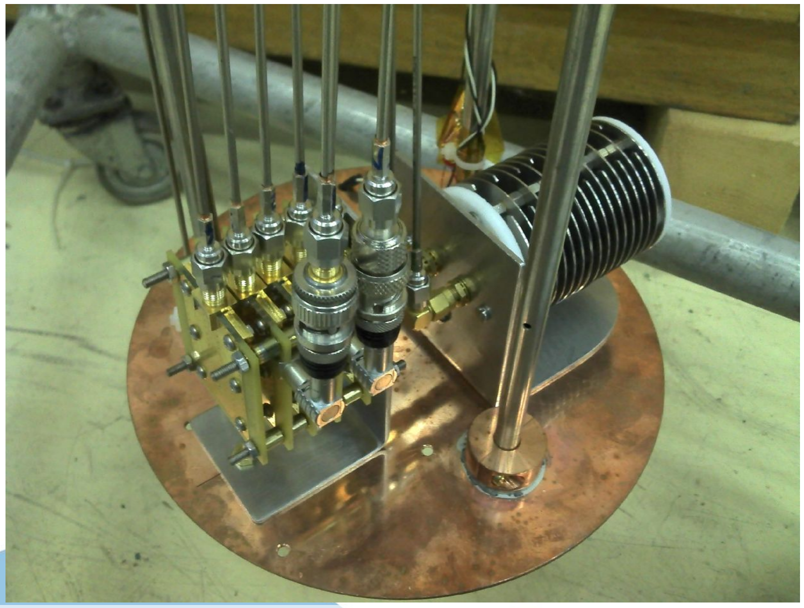
Signal from LHC Diamond BLM



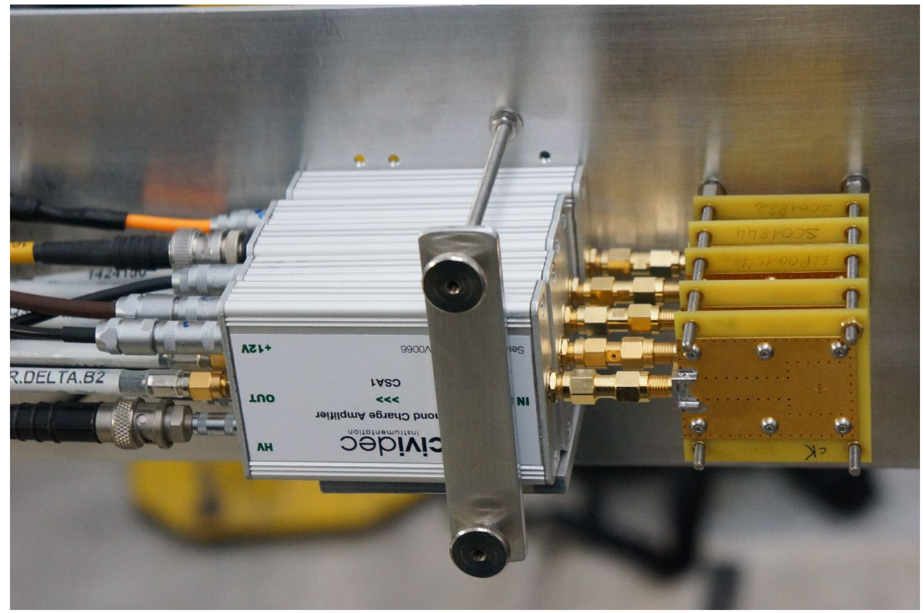
Courtesy Maria Hempel

Low intensity beam
Setup 2012

In liquid helium



At room temperature



Semiconductors:

Silicon p^{+}-n-n^{+} with 300 µm thickness and single crystal chemical vapor deposition (CVD) **Diamond** with 500 µm thickness

LHe chamber

3.9 cm active length

With **Erich Griesmayer** and **Christina Weiss**

Allowed to understand detector properties. Results in 2013...

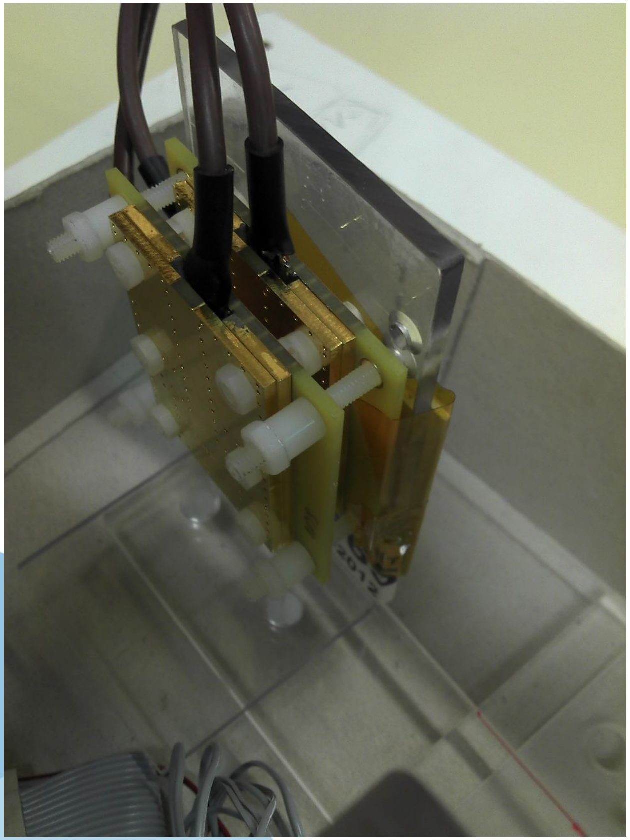
Main open question: Radiation hardness of semiconductors at 1.9 K?

Room temperature irradiation

- **24 GeV/c protons** from PS
- 400 ms spill duration
- $1.5 \cdot 10^{11}$ protons/cm^2/spill
- **30°C** at detector placement (Sauna conditions for Silicon material)
- Measurement procedure:
  - DC measurements of Silicon and Diamond in parallel from beam particles with Keithley 6517
  - Offline integration of the charge

→ DC and RT: **Unfavorable conditions for Silicon**

Room temperature irradiation
Setup picture



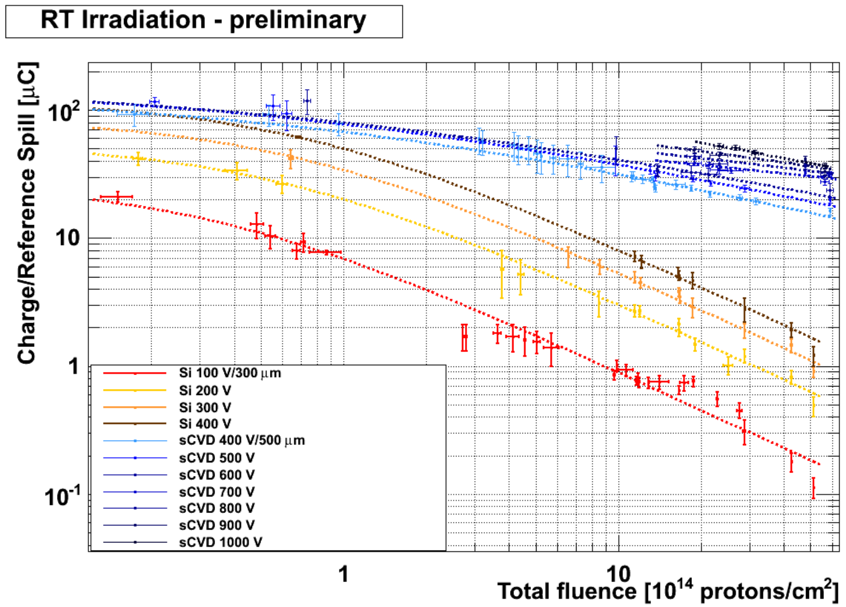
10 kΩcm **Silicon** p^+-n-n^+,
300 µm and

Single crystal CVD
Diamond 500 µm

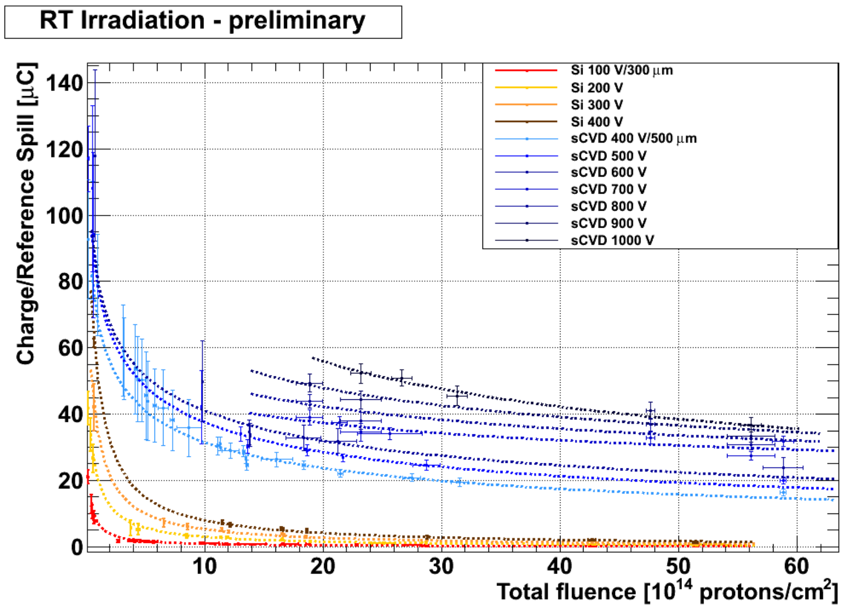
First spills higher signal from Silicon, but situation changed quickly...

Room temperature irradiation results

Double log



linear



Best fit for Silicon:

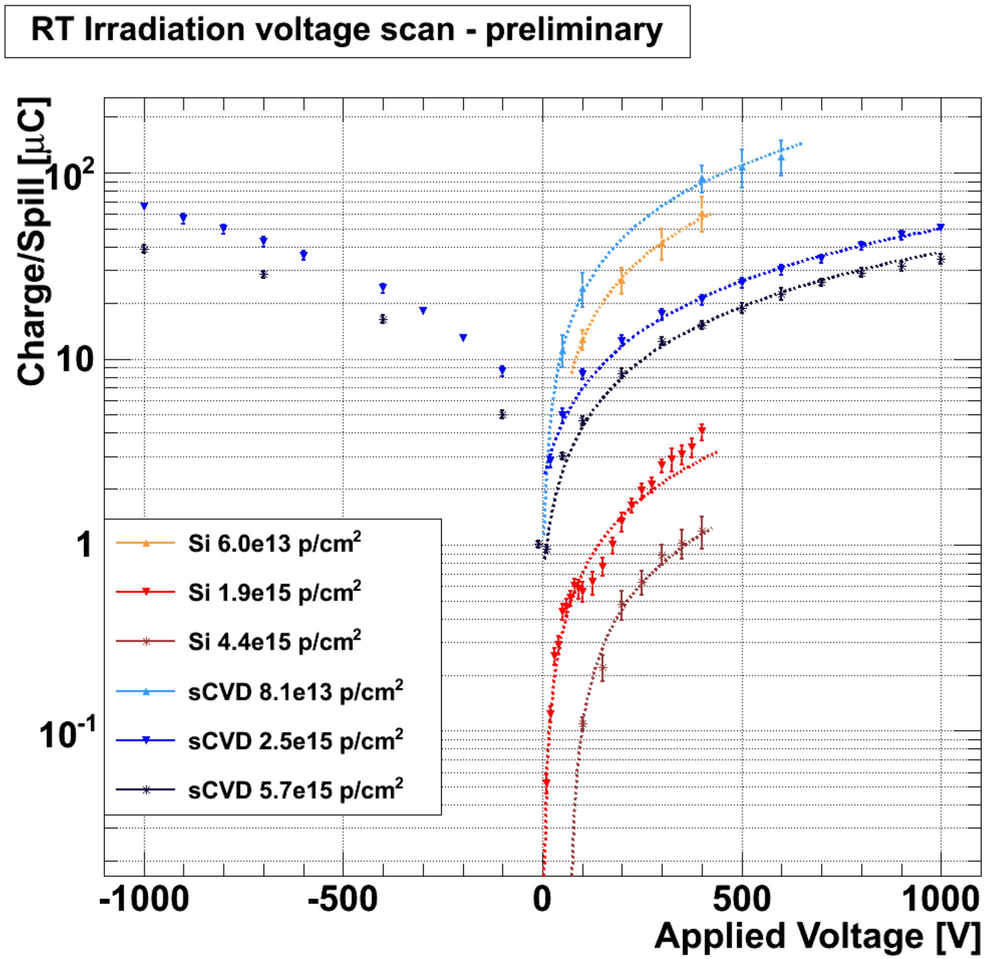
$$Q(\phi)=\frac{Q_0}{1+k\,\phi\,Q_0}$$

Best fit for Diamond:

$$Q(\phi)=\frac{Q_0}{1+\phi^k Q_0}$$

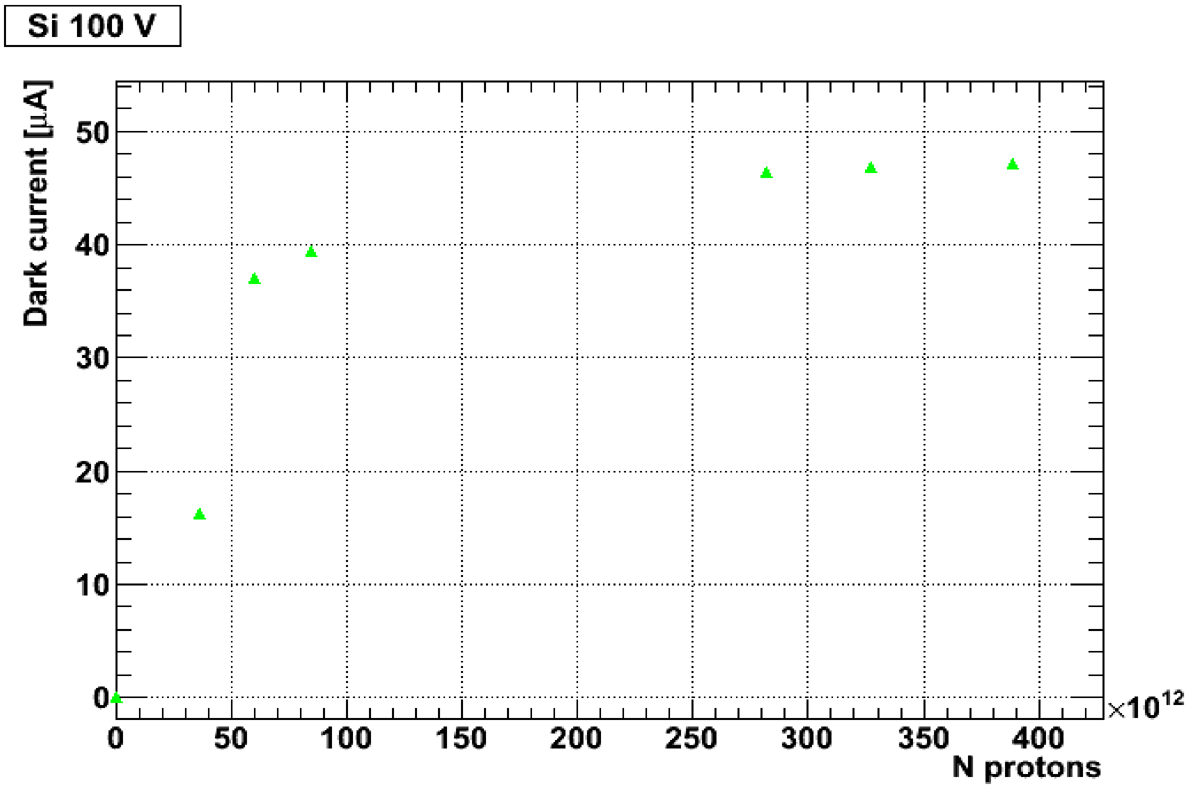
More comparisons to come

Voltage scans



No full CCE even at high bias

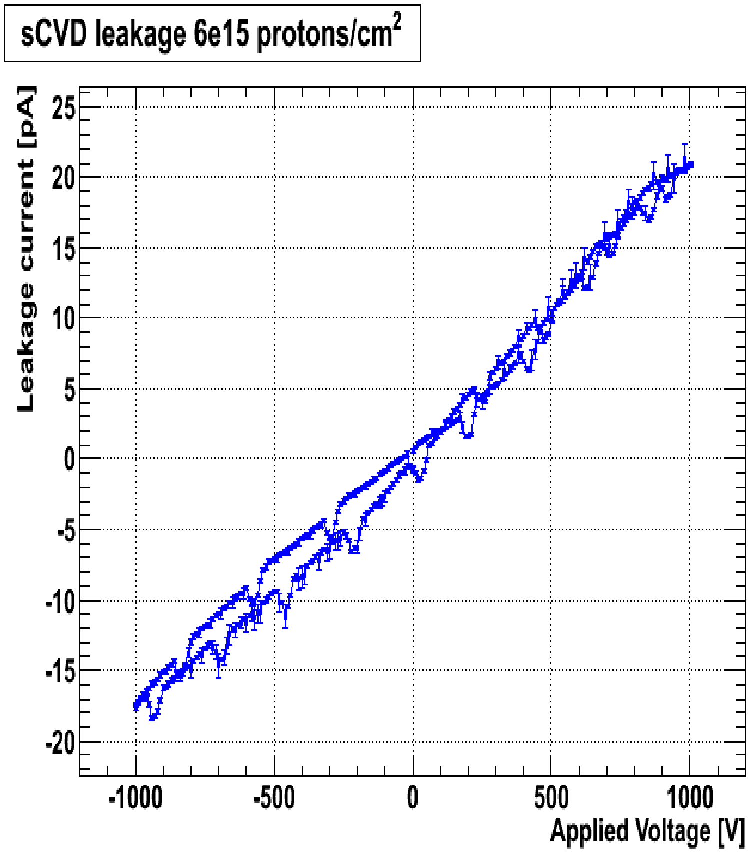
Si leakage

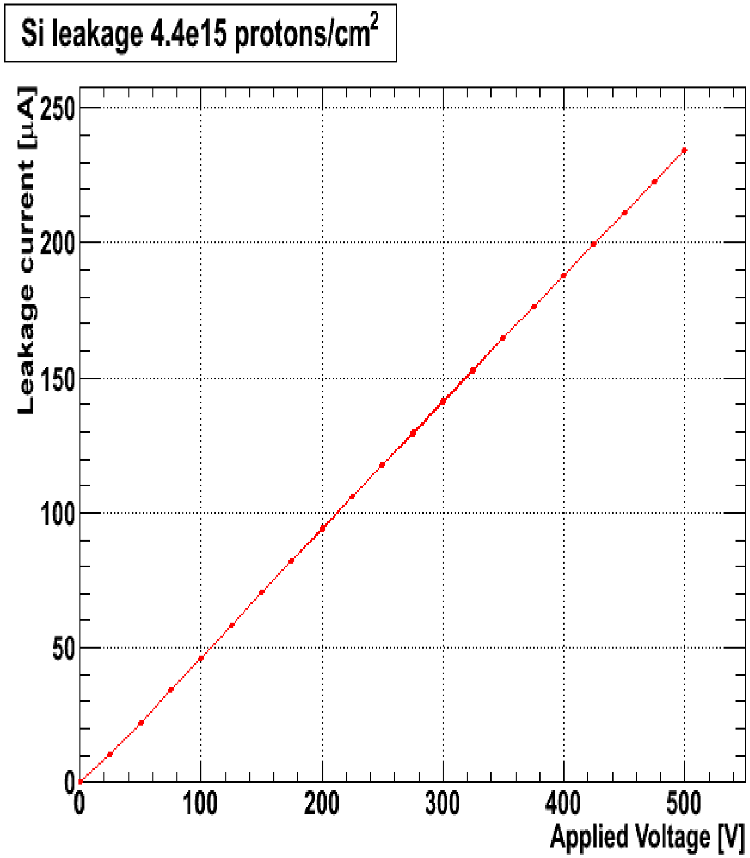


Fast increase of leakage current due to temperature and irradiation:

- Before irradiation: **40 nA** at 100 V
- After irradiation: **48 μA** at 100 V

Leakage current





7 orders of magnitude larger leakage
for Si compared to Diamond

Cold Irradiation

- In cold Silicon leakage should go down to pA, even for highly irradiated samples
- DC measurements in cold are therefore a valid comparison between Si and Diamond
- In addition to DC, laser TCT for Si at certain fluencies

- Irradiation ended yesterday morning at a total fluency of $1.3 \cdot 10^{16}$ protons/cm^2 (Silicon IV shows **1 mA at 100 V** at 25°C, while sCVD is still **below 100 pA at 500 V**)

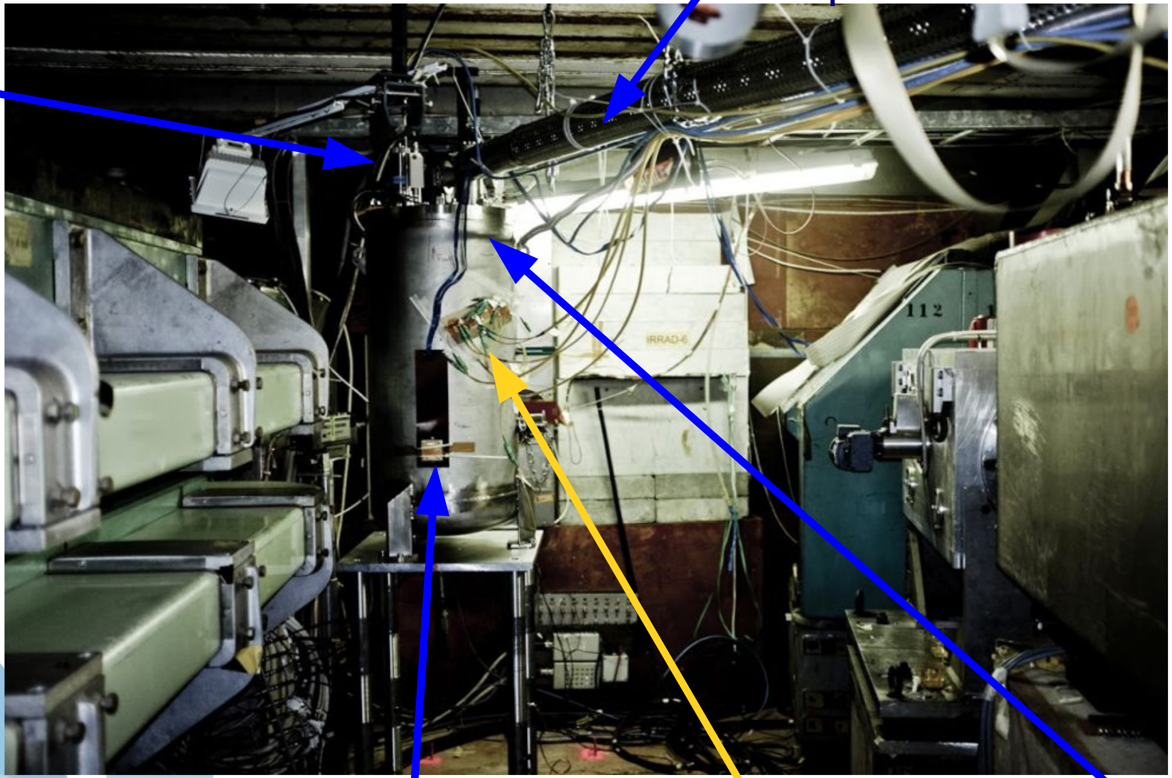
Installation in radiation zone

Limited space, heavy material, 30°C, radioactive zone, protection cloths
→ Sauna conditions for human material

Final irradiation setup

Helium transfer and recuperation line

Feedthroughs for:
- 15 Optical fibers
- 21 Electrical cables



BPM

Optical fibers

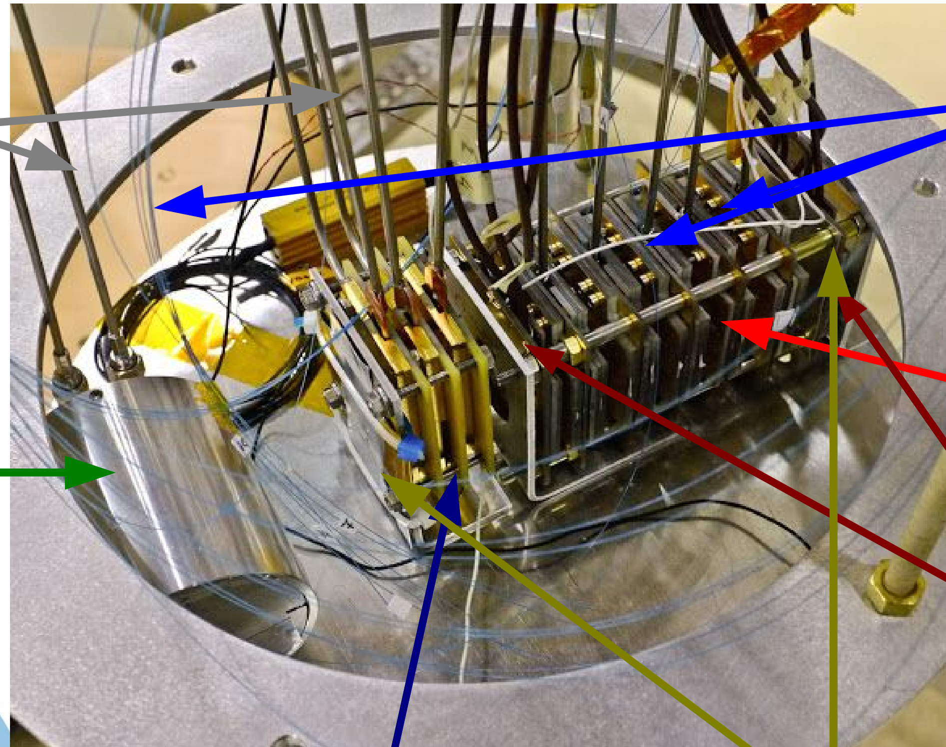
Cryostat

Continuous monitoring of beam properties, temperature, helium level and pressure

Inside cryostat - detectors

UT85 Stainless steel cables for low heat introduction

Liquid helium chamber



Radiation hard optical fibers

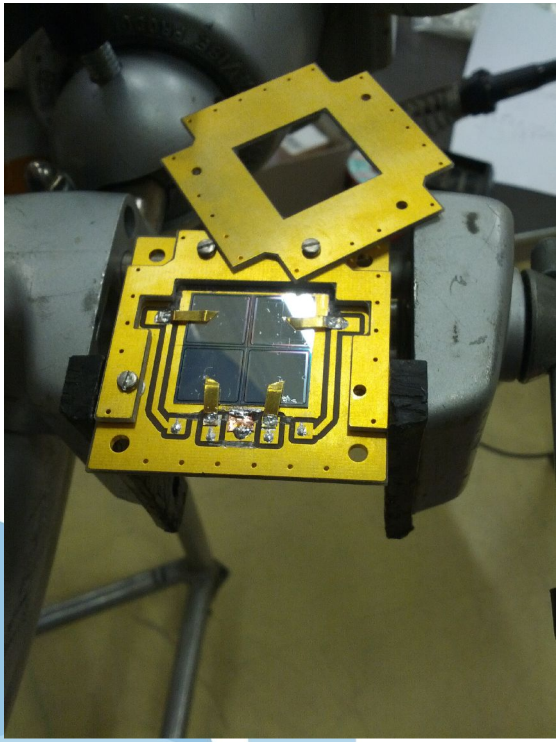
5 Silicon laser TCT setups

2 Silicon telescopes

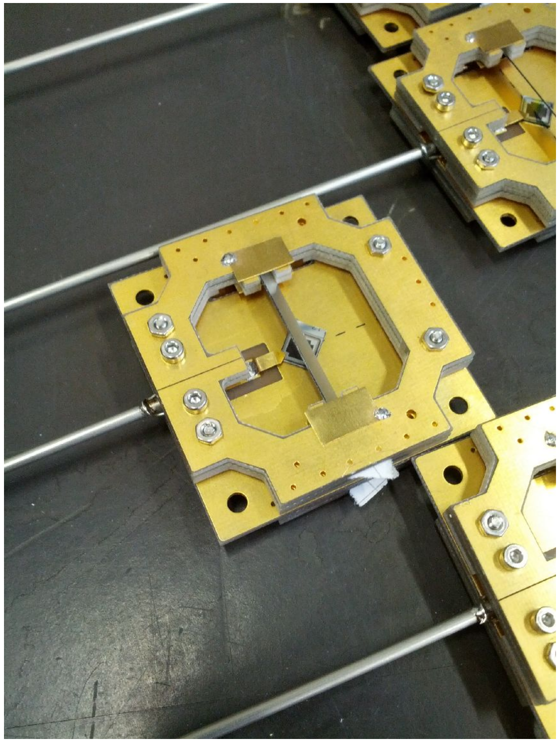
2 sCVD and one 10 kΩcm Silicon

Aluminum foils for dose calculation after irradiation

Si devices from V. Eremin



Telescope

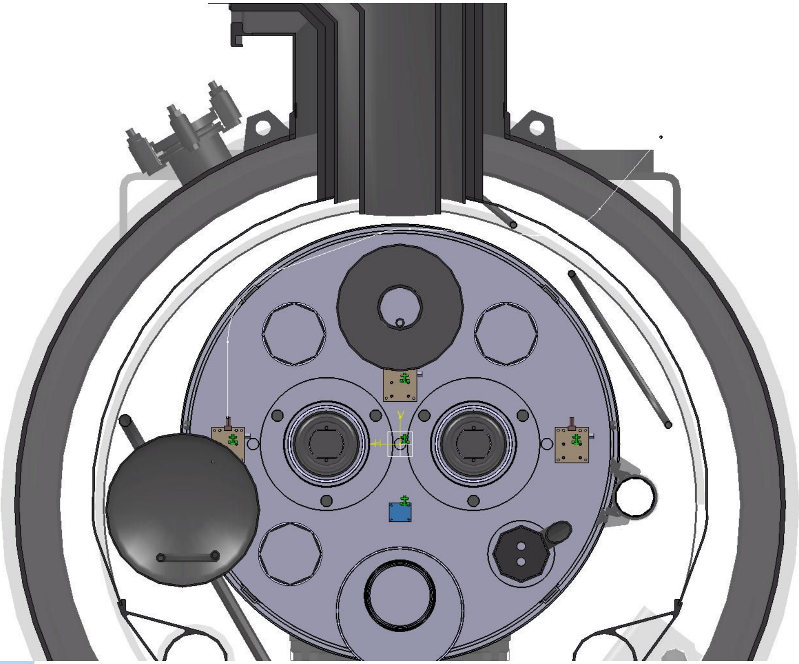


Different resistivity
Silicon with laser TCT

Remarks and observations

- Fascinating opportunity to observe Diamond and Silicon in parallel at different fluencies and different temperatures
- **Silicon leakage below 100 pA** at liquid helium temperatures and even under high irradiation
- **Stable operation of Diamond**, comparable damage constant at RT and liquid helium
- Damage constant of Si larger than of sCVD, but much smaller difference than at RT
- Much more still to come...

First cryogenic LHC detectors on cold mass of the magnet

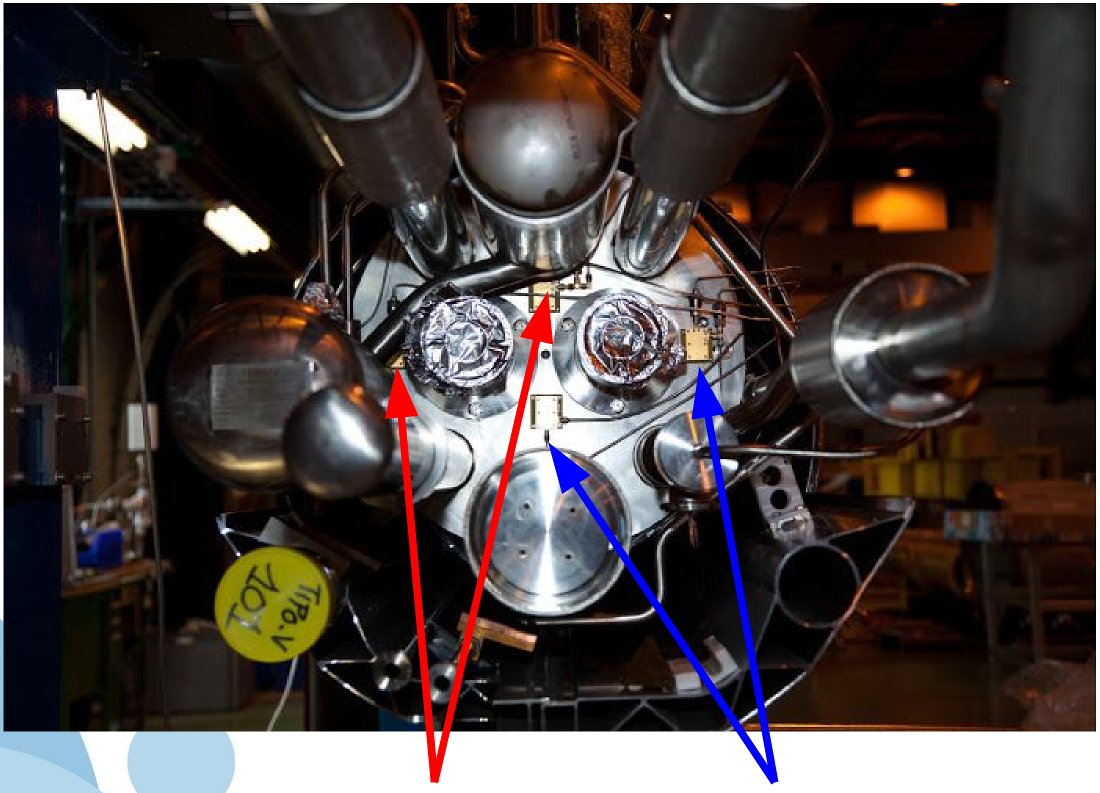


Technical drawing
Thierry Renaglia

Installation of 2 Silicon and 2 Diamond detectors in Q7R3 at 1.9 K. Magnet will be exchanged during long shut down 1.

Further placement planed in DS L3 during LS1.

LHC detectors in Q7R3



Two Silicon detectors   Two sCVD detectors

Conclusion

- Advantage of Diamond at RT for DC measurements obvious
- Further analysis and comparisons will allow conclusions for CryoBLM
- First LHC detectors will allow:
  - Detector performance test
  - Long term stability study
  - Unprecedented LHC loss insight

Co-authors/Acknowledgements
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