Radiation Hard Cryogenic Silicon Detectors: The Lazarus Effect

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on behalf of the
CERN-RD39 Collaboration
http://www.cern.ch/RD39

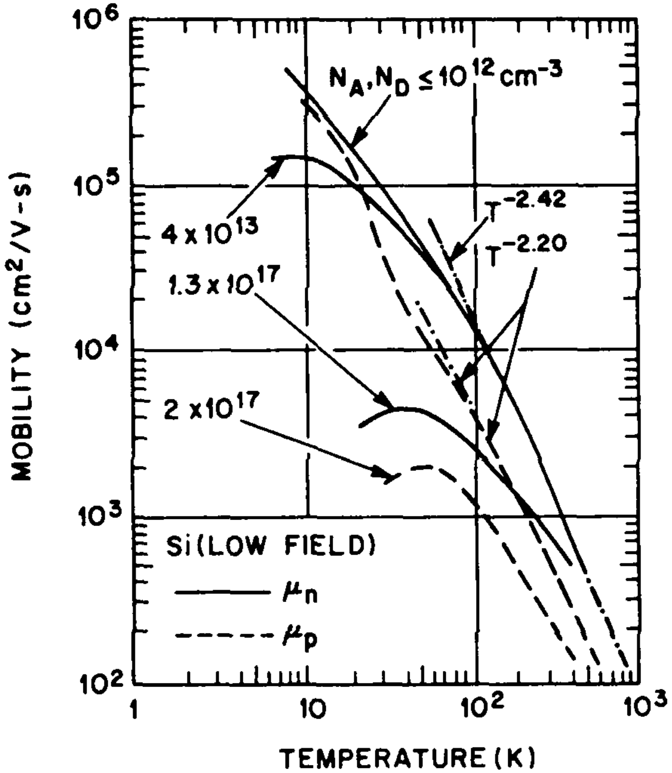
Outline

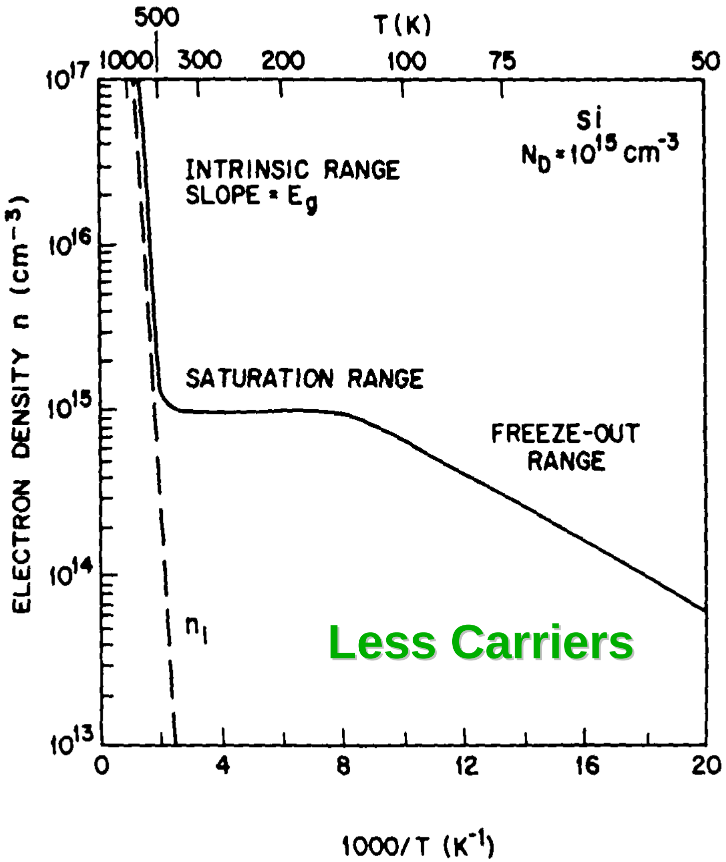
- Known facts about silicon detectors operated at cryogenic temperatures
- Electric passivation of radiation induced defects in silicon: the Lazarus effect
- Silicon detectors optimized for the cold
- Position resolution of a “resurrected” detector
- “Low mass” cryogenic cooling systems
- First application of a cryogenic silicon tracker in a high energy physics experiment
- Innovative concepts
- Conclusions

Known facts about silicon detectors operated at cryogenic temperatures ...

Properties of Silicon at Cryogenic Temperatures

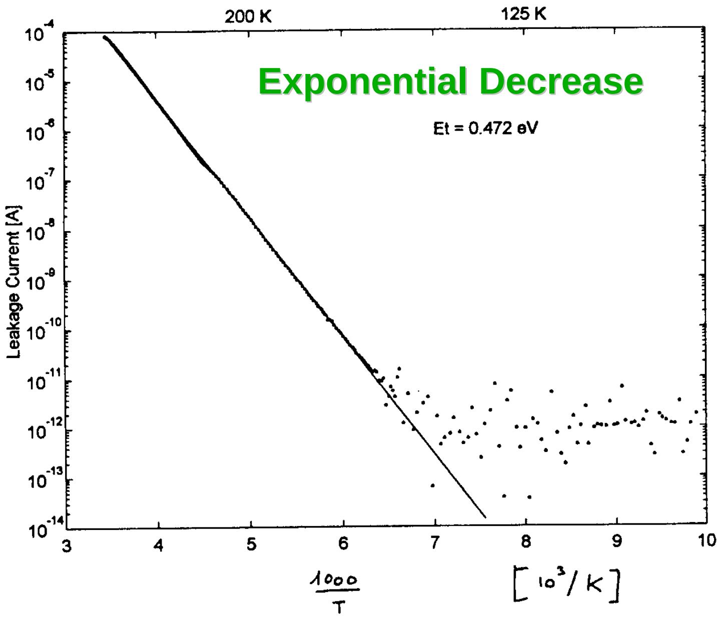
Higher Mobility

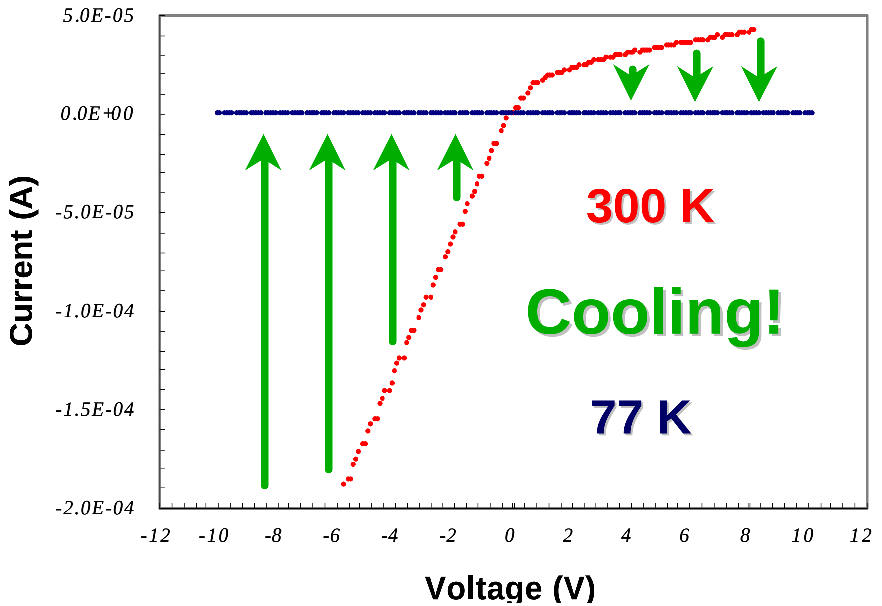




Less Carriers

Radiation Induced Leakage Current Reduction with Temperature



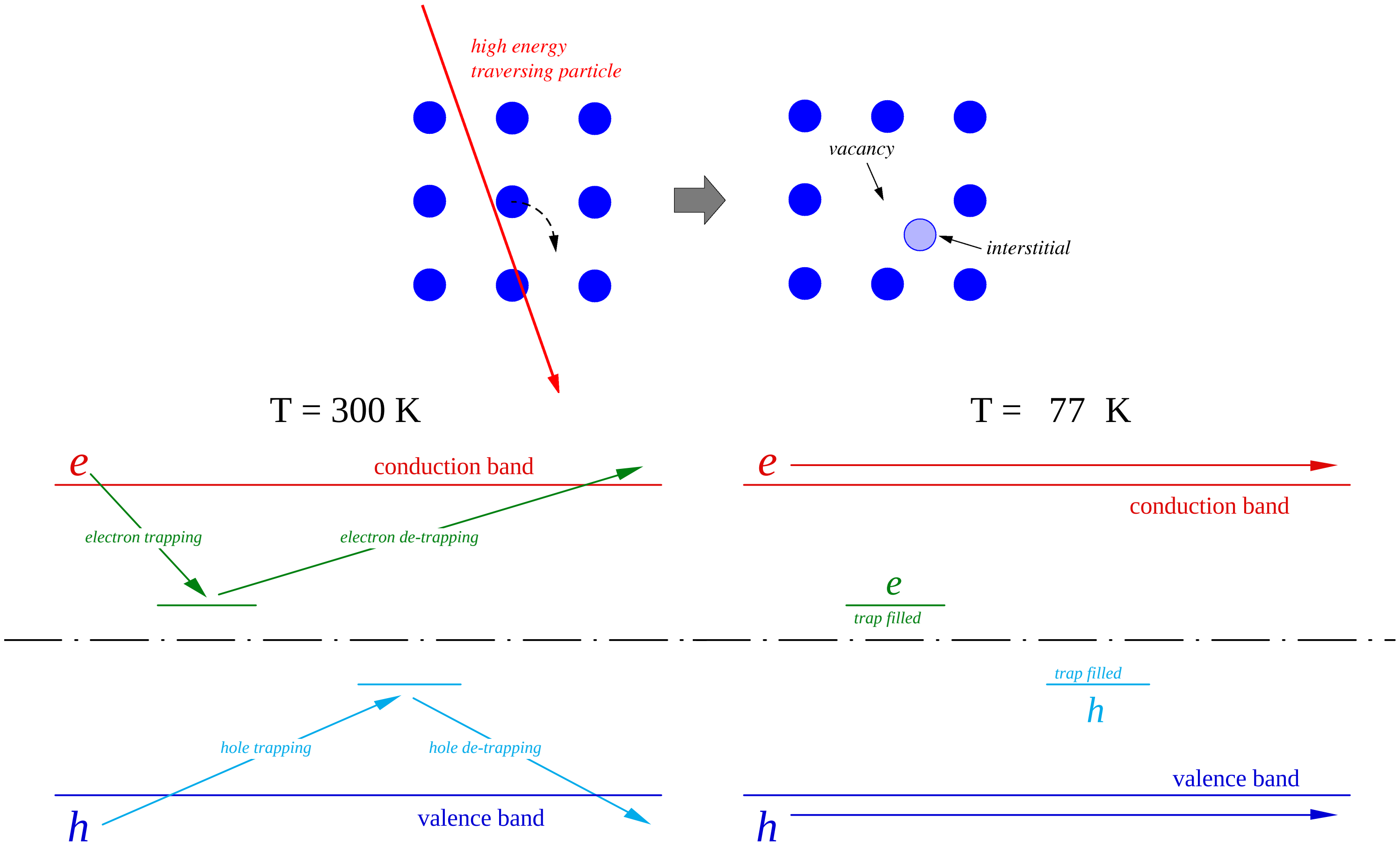


At 77 K, detectors irradiated above $5 \cdot 10^{14}$ n/cm^2 show less than 1 nA current in the bias range ± 500 V

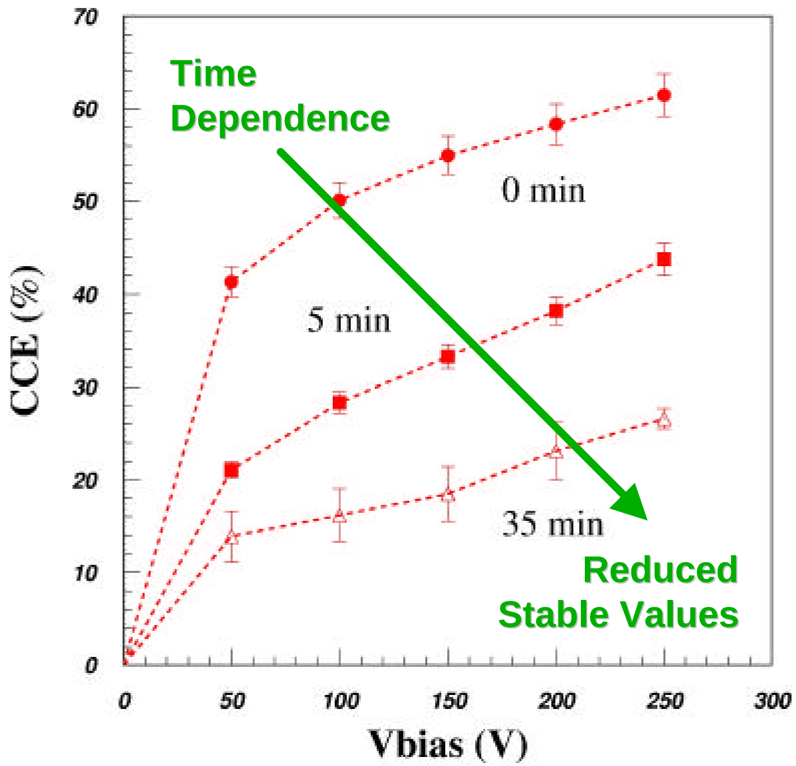
Is there anything else ?

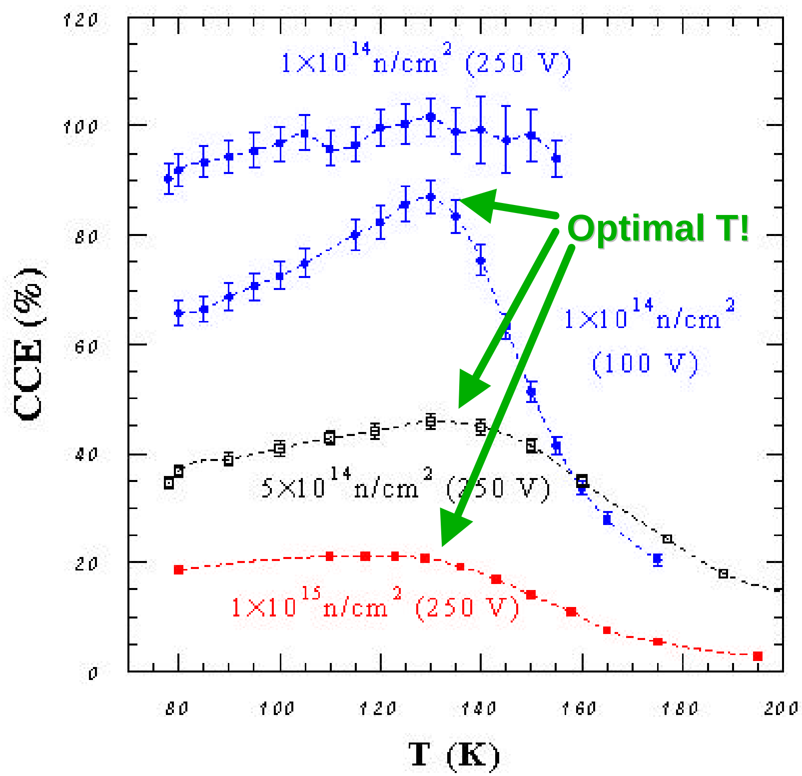
…

Electric Passivation of Radiation Induced Defects



Conventional Operation





$$\left\{ 300mm\, 10^{15} n/cm^2 + 130K + 250\,V = 25000\, e^- \cdot 20\% = 5000\, e^- \right\}$$

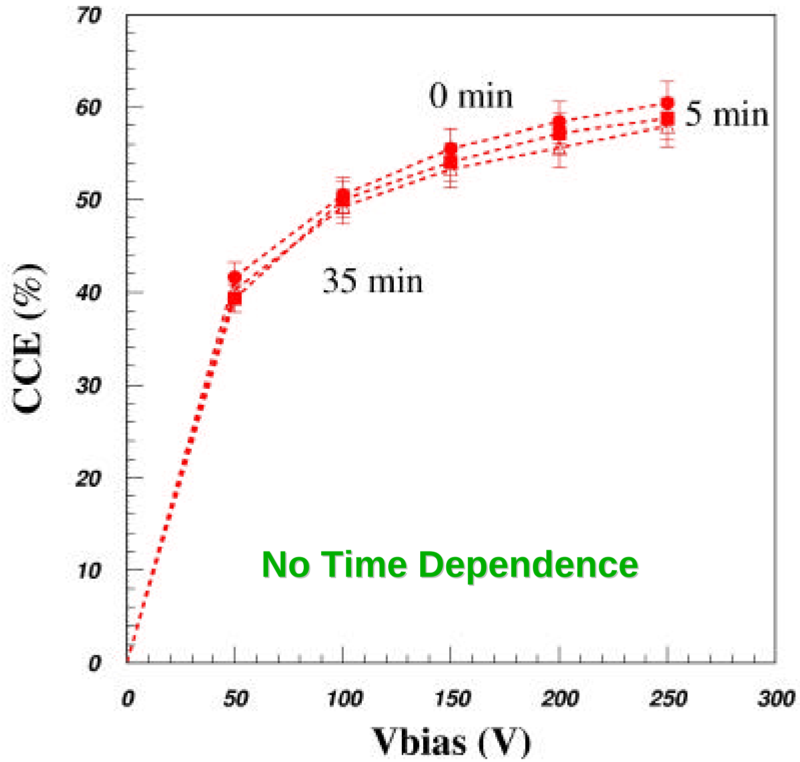
The Lazarus Effect !

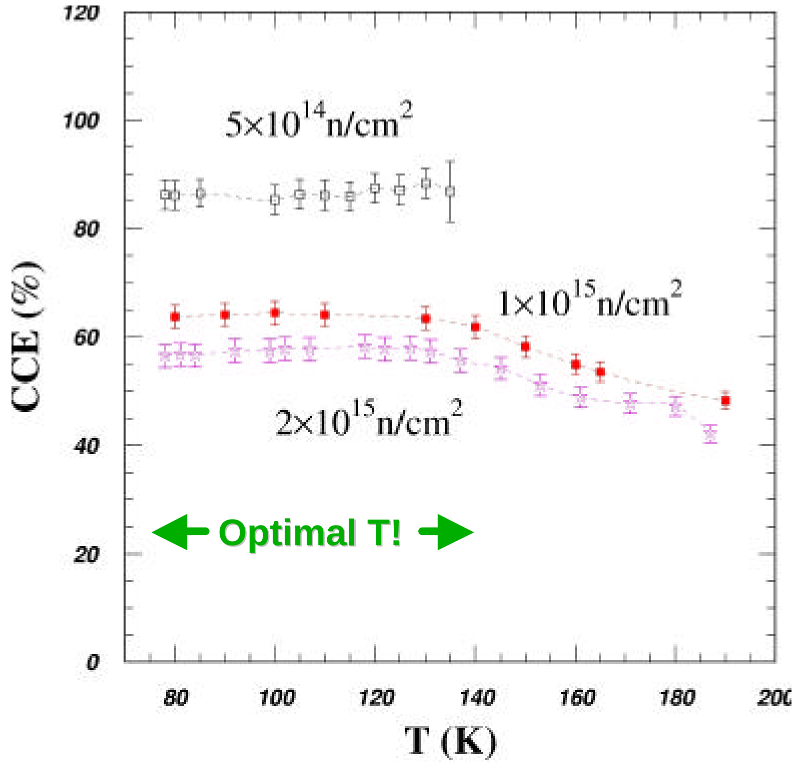
Is cryogenic silicon a new material ?

if yes …what can we do with it ?

Non-Conventional Operation

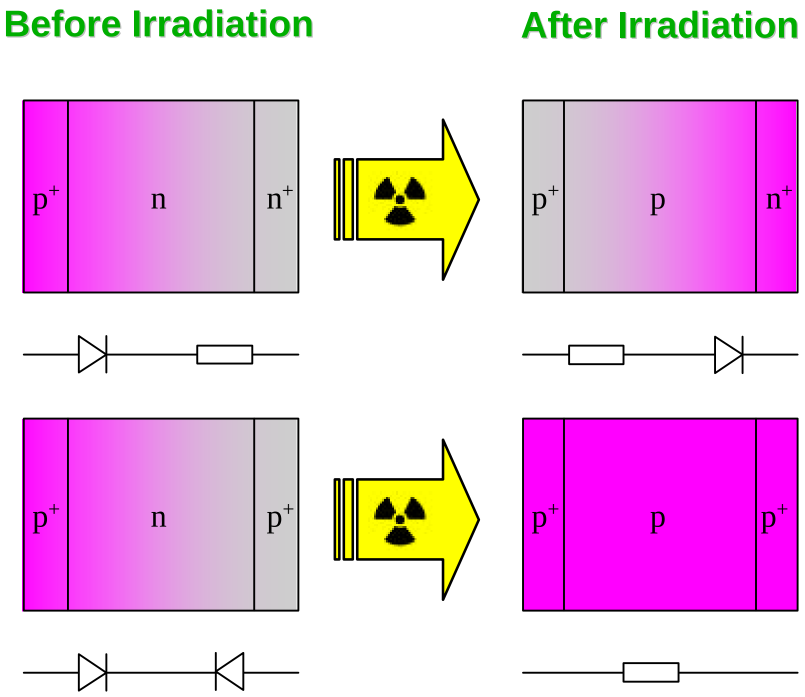
Forward Bias

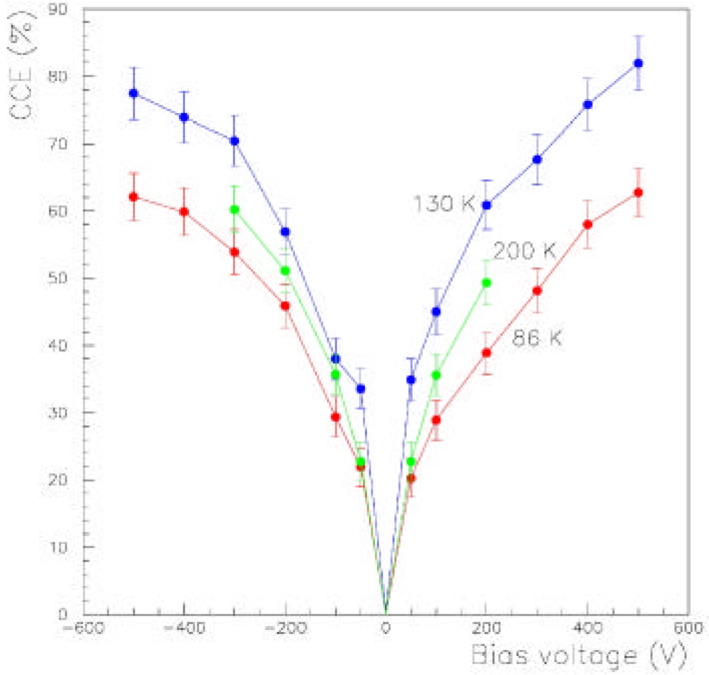




$$\left\{ 300mm\, 10^{15}\, n/cm^{2} + 130K + 250\,V = 25000\, e^{-} \cdot 60\% = 15000\, e^{-} \right\}$$

"Double P" Detector

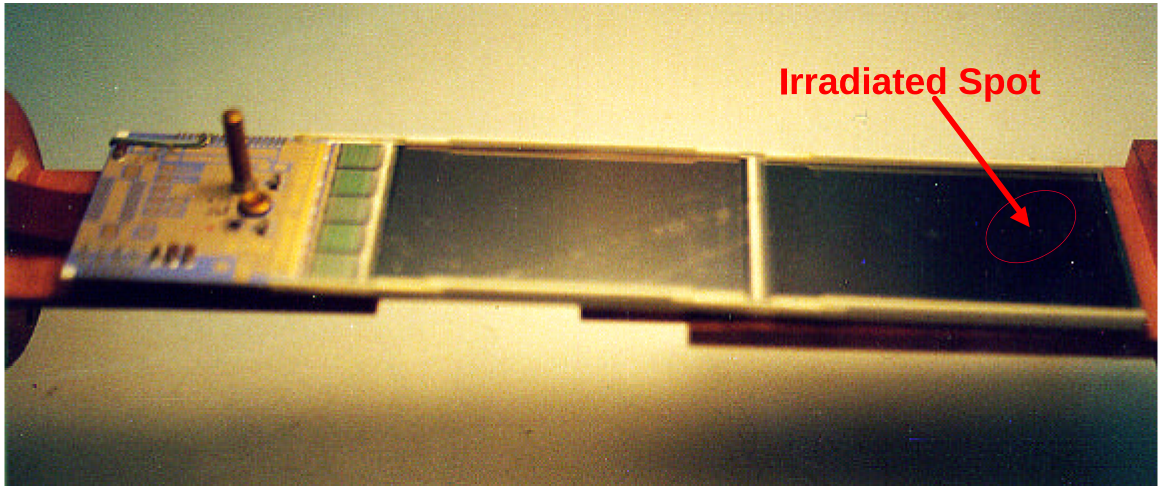


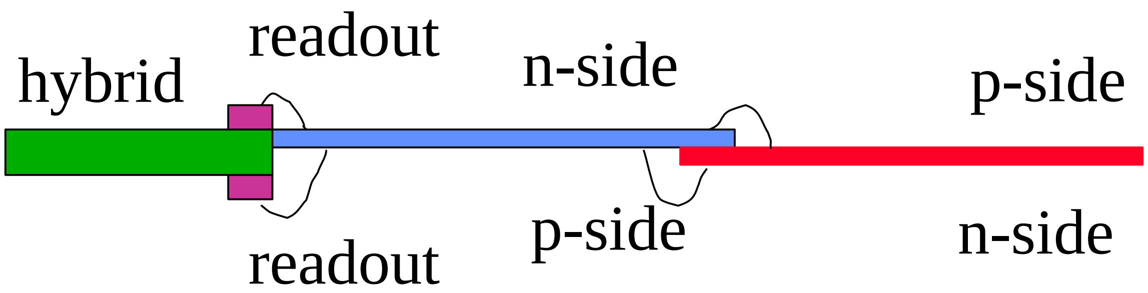


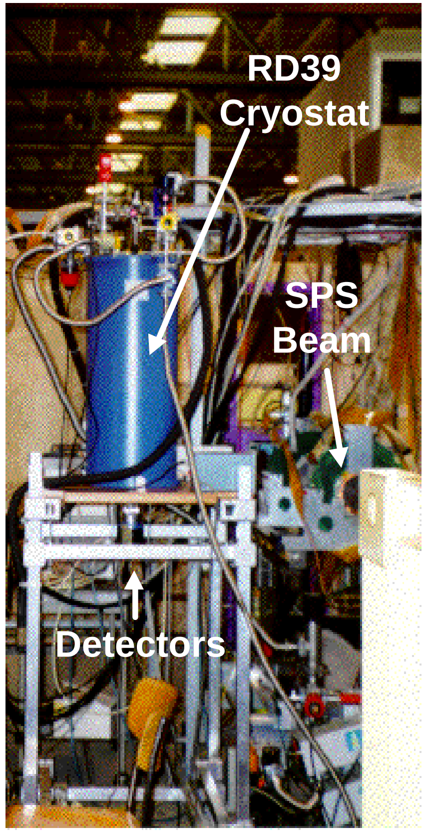
$$\left\{ 400mm\, 10^{15} n/cm^2 + 130K + 500\,V = 33000\, e^- \cdot 80\% = 27000\, e^- \right\}$$

The charge is back, but what about position resolution ?

The Cooled DELPHI Microstrip Detector Module



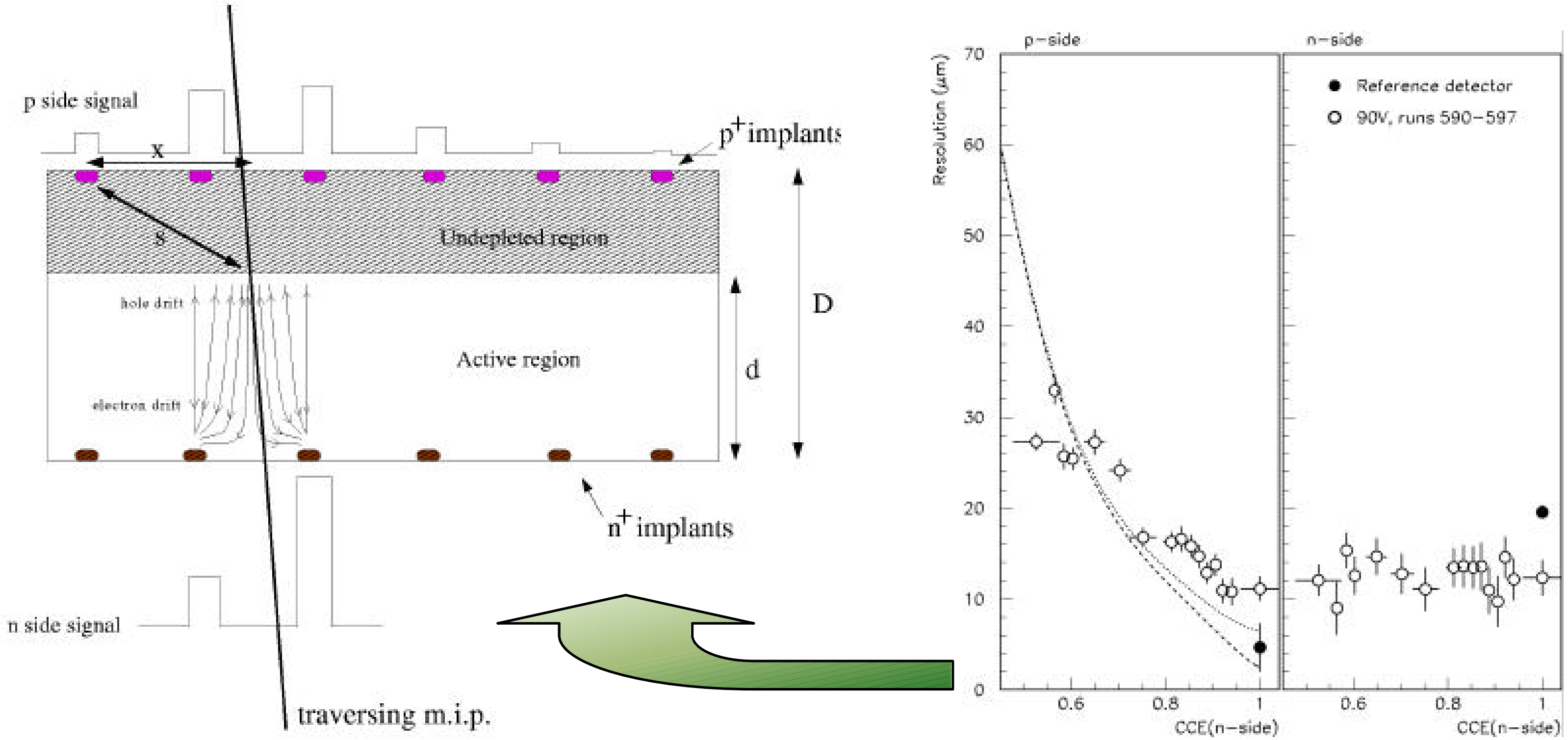




3x12 cm^2; 1280 Channels CMOS readout

K. Borer et al, NIM A **440** (2000) 17

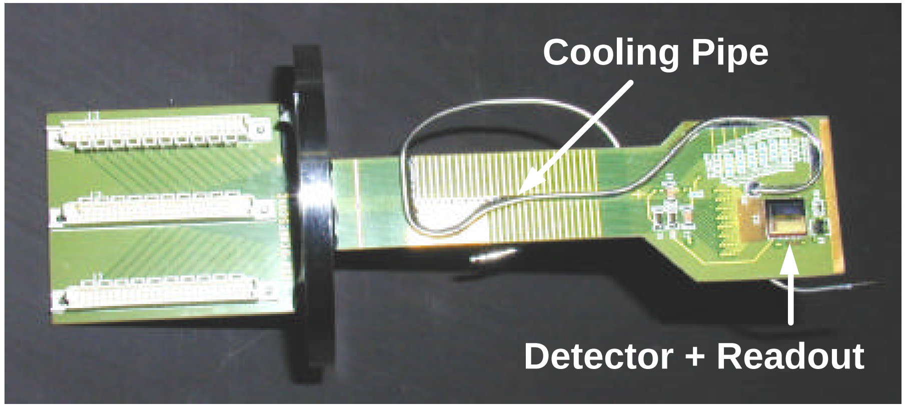
Position Resolution



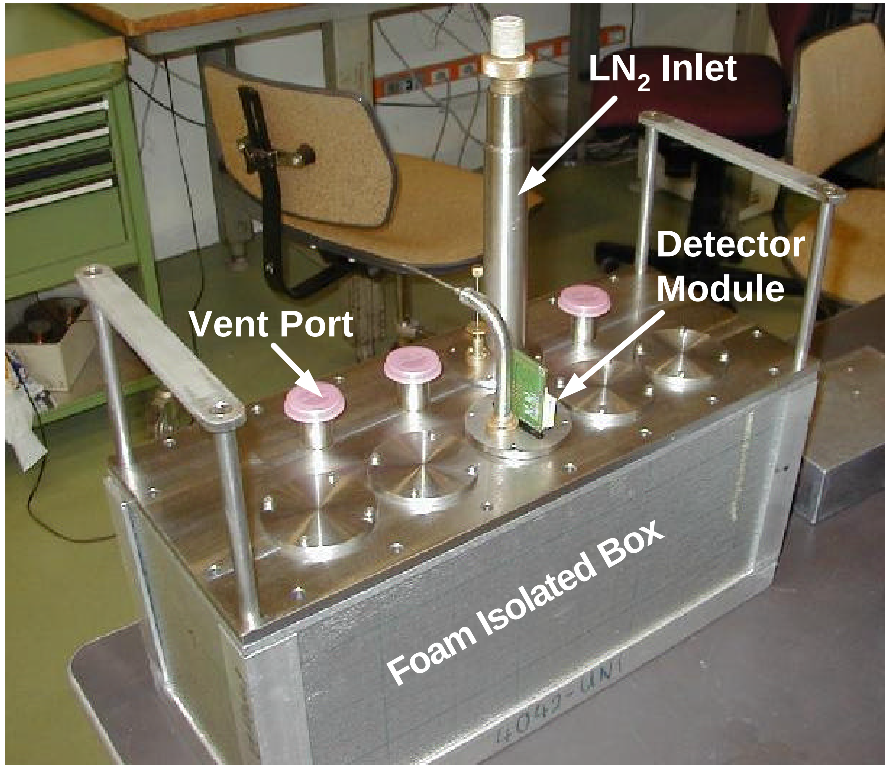
Cryogenic cooling of a segmented detector results also in recovering the tracking position resolution!

Is a “low mass” cryogenic system feasible ?

Towards a “Low Mass” Cooling System



Liquid nitrogen is a very good coolant



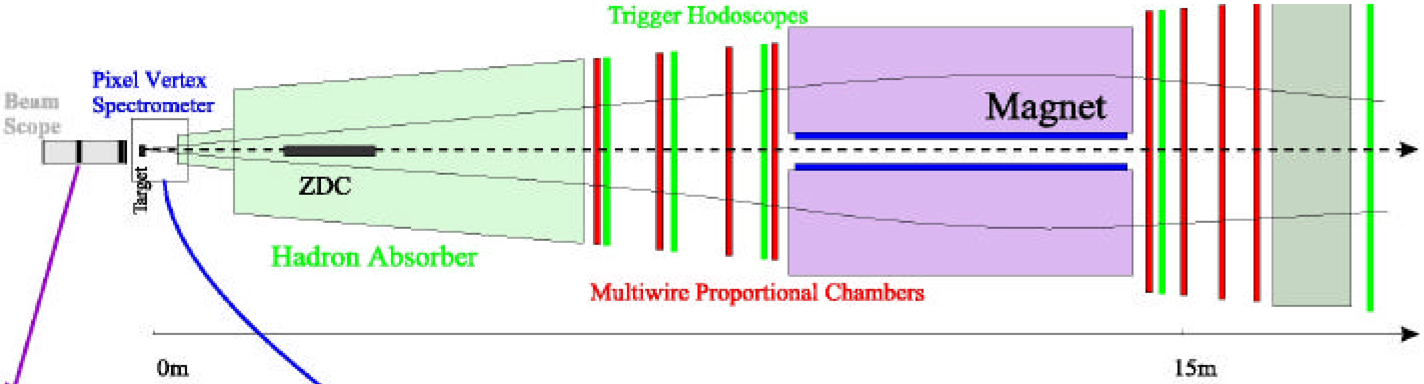
The cooling pipe is “low mass” (1 mm Æ 100 mm thick)

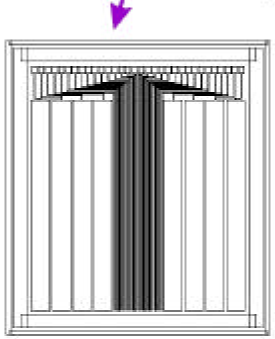
Integrated thermal/electric design for the PCB/Hybrid improves performances
No dissipation in the sensor means no need for cooling

For 130 K operation, foam isolation (30 mm thick) plus dry gas atmosphere is sufficient

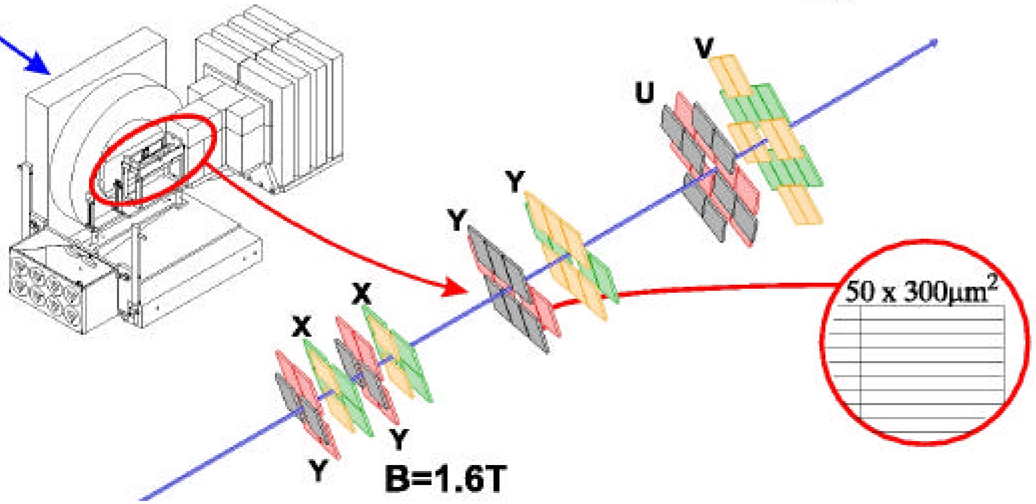
The first application:

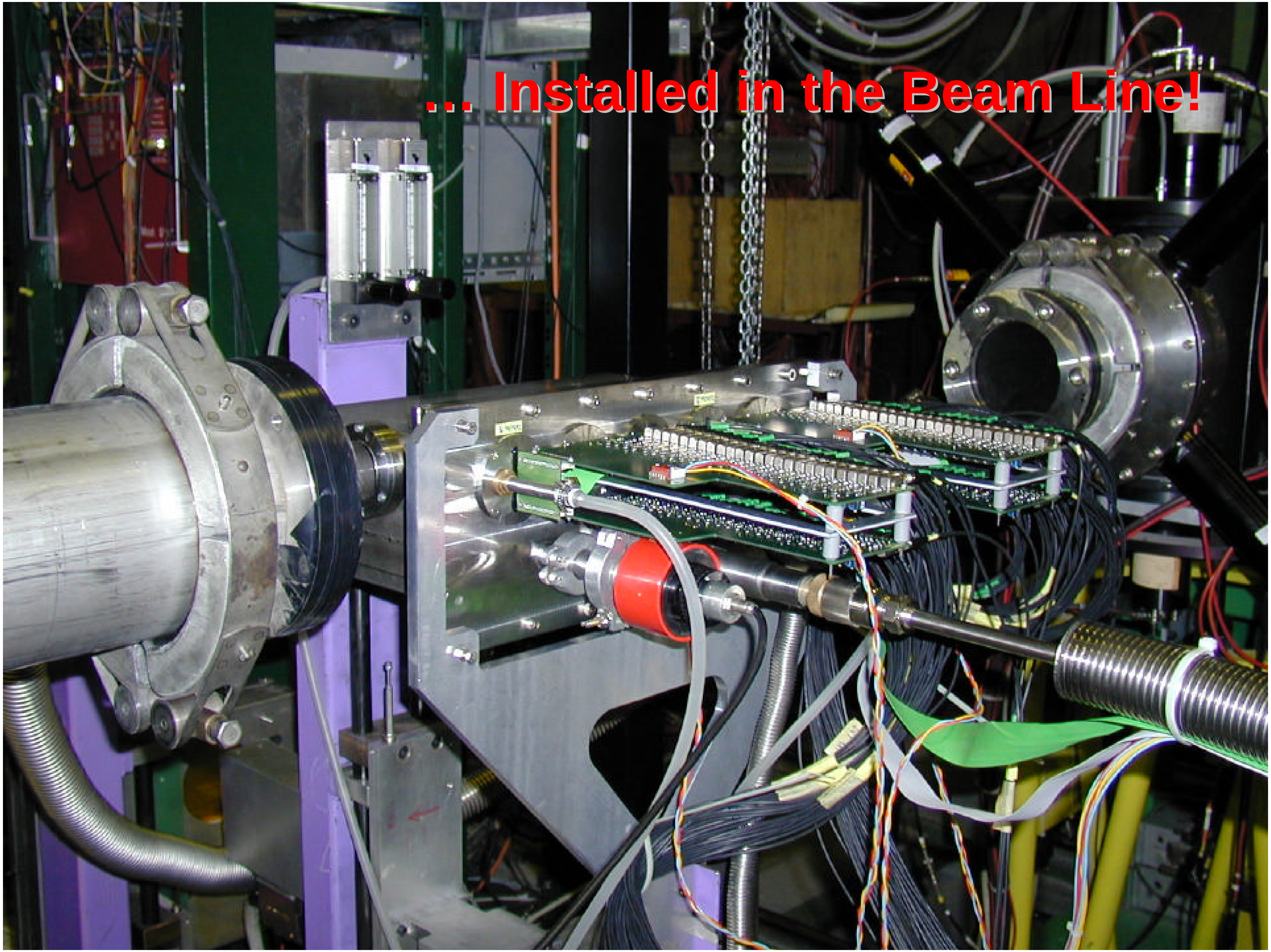
The BeamScope for the CERN NA60 Experiment …





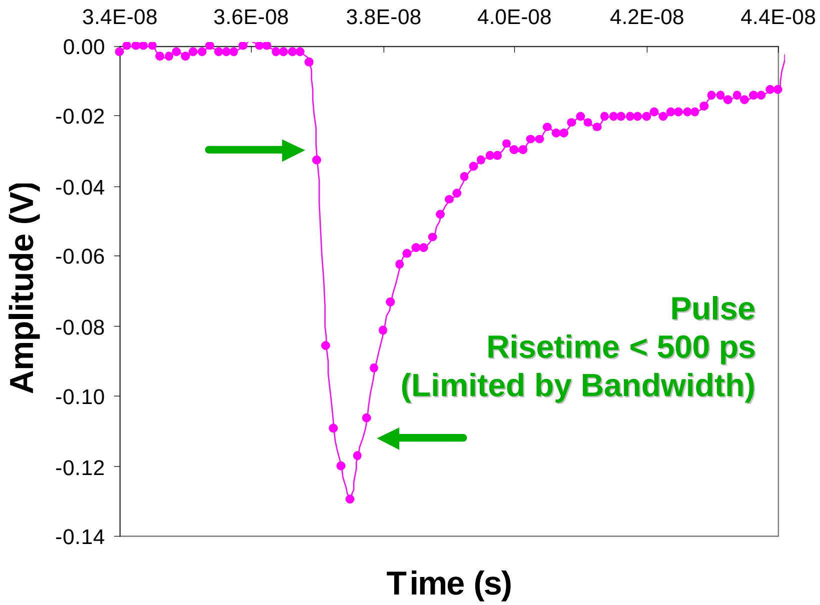
RD39 BeamScope

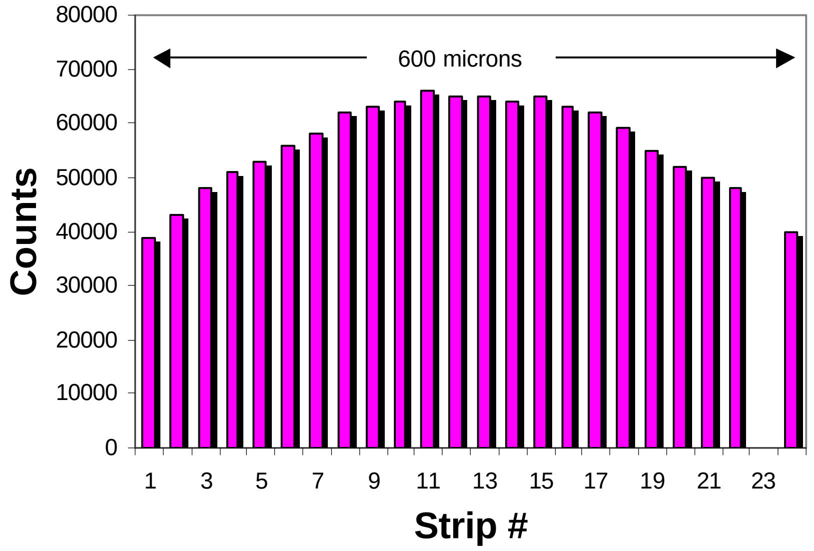



… Installed in the Beam Line!

The CERN SPS High Intensity Pb-Ion Beam as seen by the BeamScope

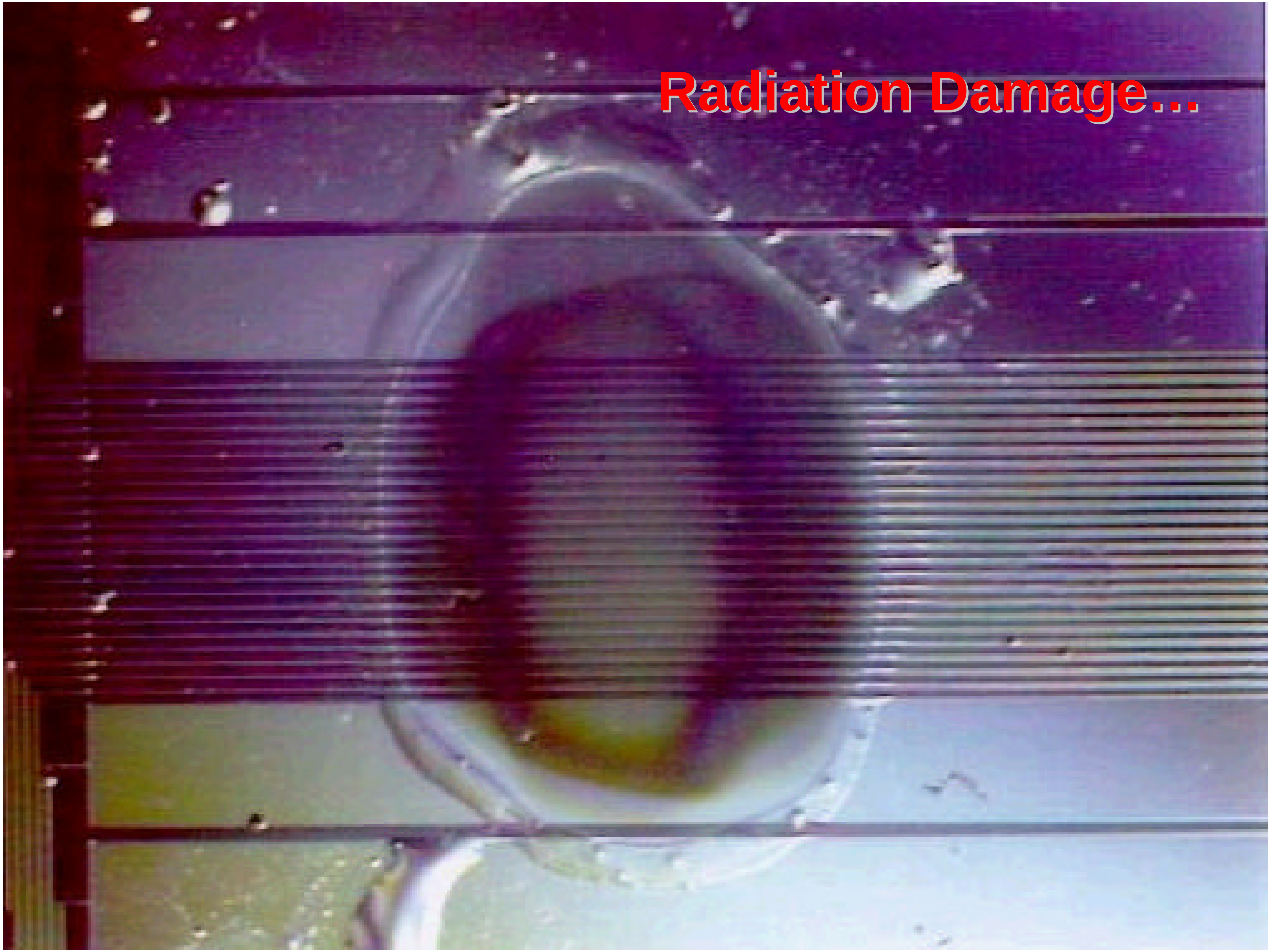
Using a strip pitch of 50 μm, we have measured the beam profile with unprecedented resolution





Using the trigger of the experiment as a reference, we could tag every single ion in the beam spill (containing $5 \cdot 10^7$ ions!)

Radiation Damage…

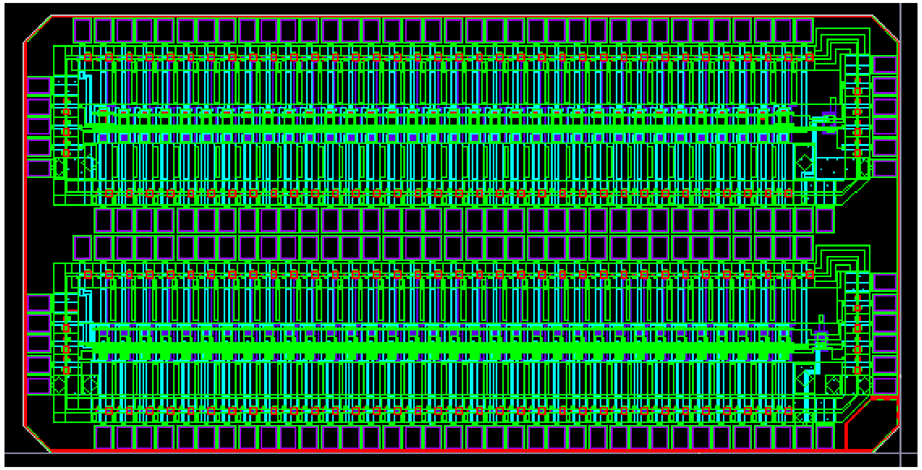


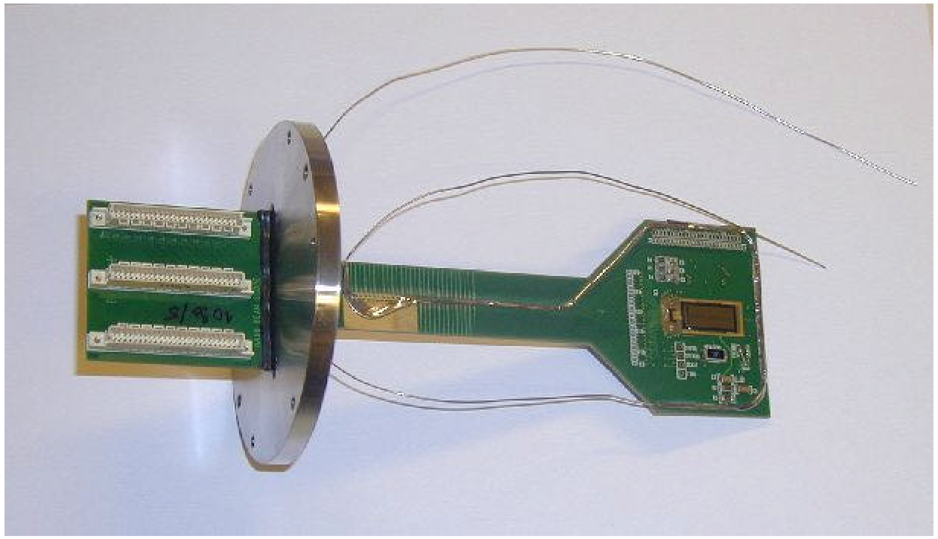
Which radiation hard readout electronics for the cold ?

The Proton Beamscope

A new front-end chip by CERN EP-MIC group manufactured in 0.25 μm radiation-tolerant CMOS technology:

- **2×4 mm^2; 32 channels**
- **peaking: ~3.6 ns at 130 K**
- **good S/N down to 2500e**
- **power dissipation: ~300mW**



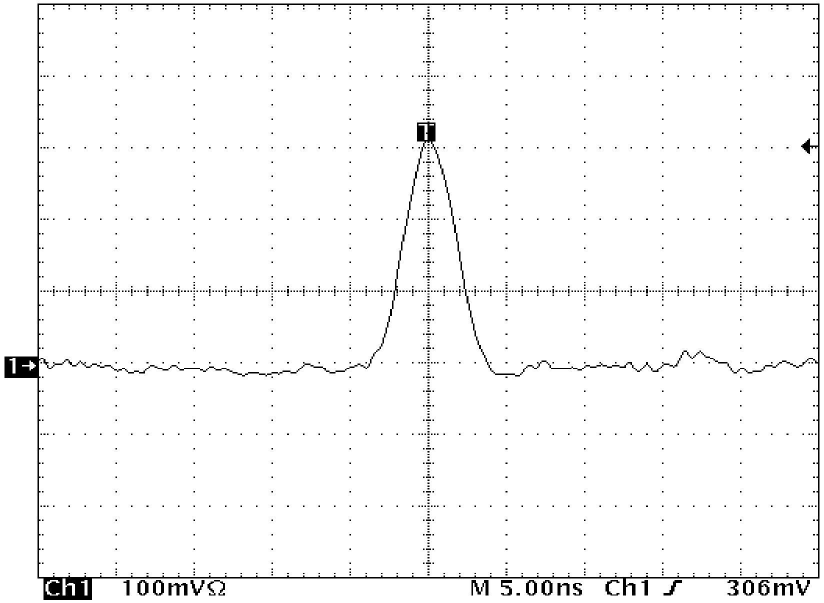


Improved module:

- **optimized microstrips**
- **new PCB design**
- **0.5 mm diameter pipes**

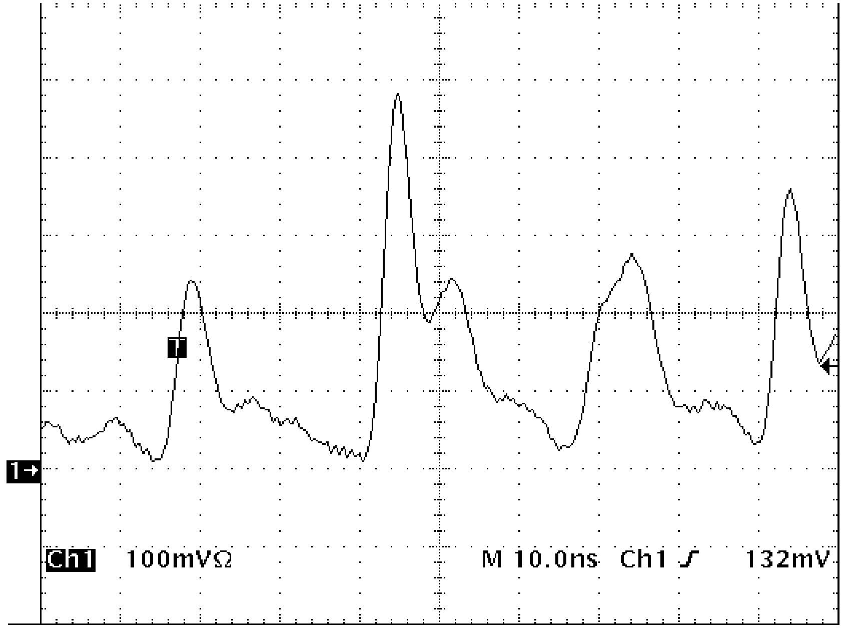
G. Anelli et al, NIM A in press

How Protons Look Like...



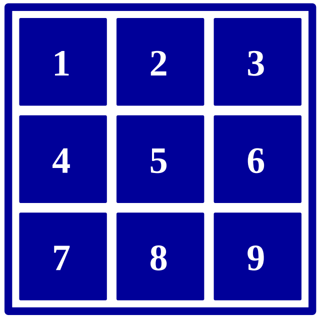
Single proton signal as seen by a fast digital oscilloscope after front-end chip and shaping stage. Extremely fast signal with good S/N

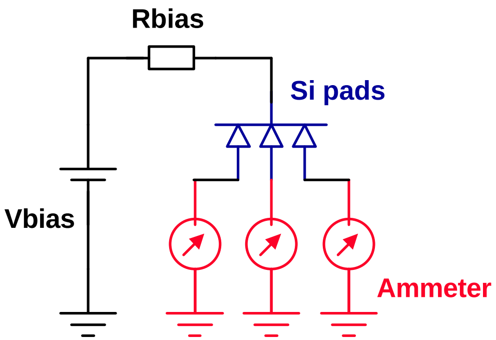
Beam intensity 10^9 protons per burst: many protons can be measured on a single detector strip without significant pile-up

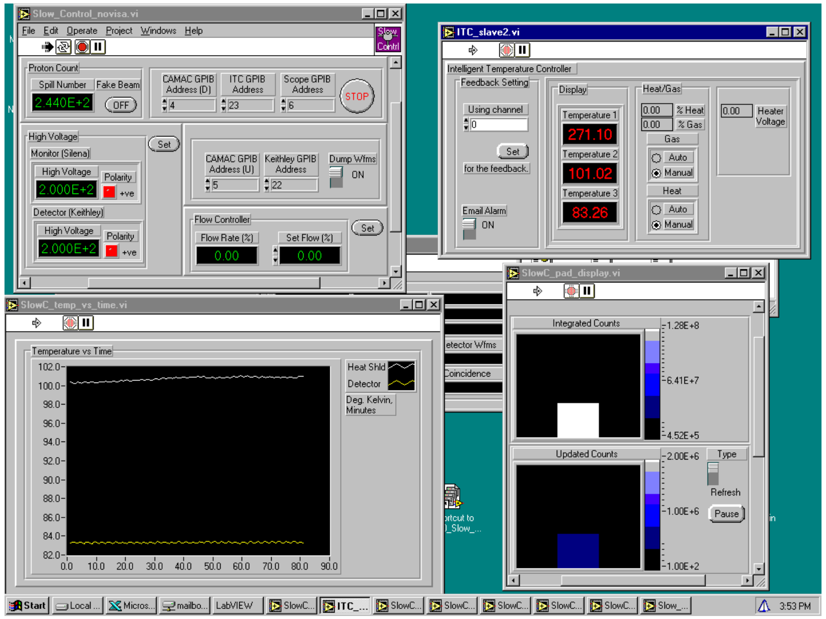


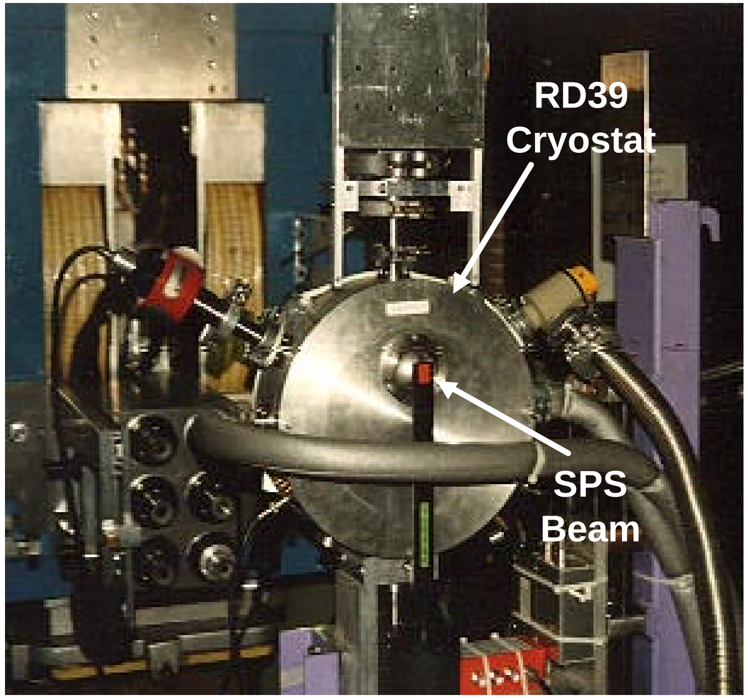
Innovative concepts:

Solid-State Ionization Beam Monitor





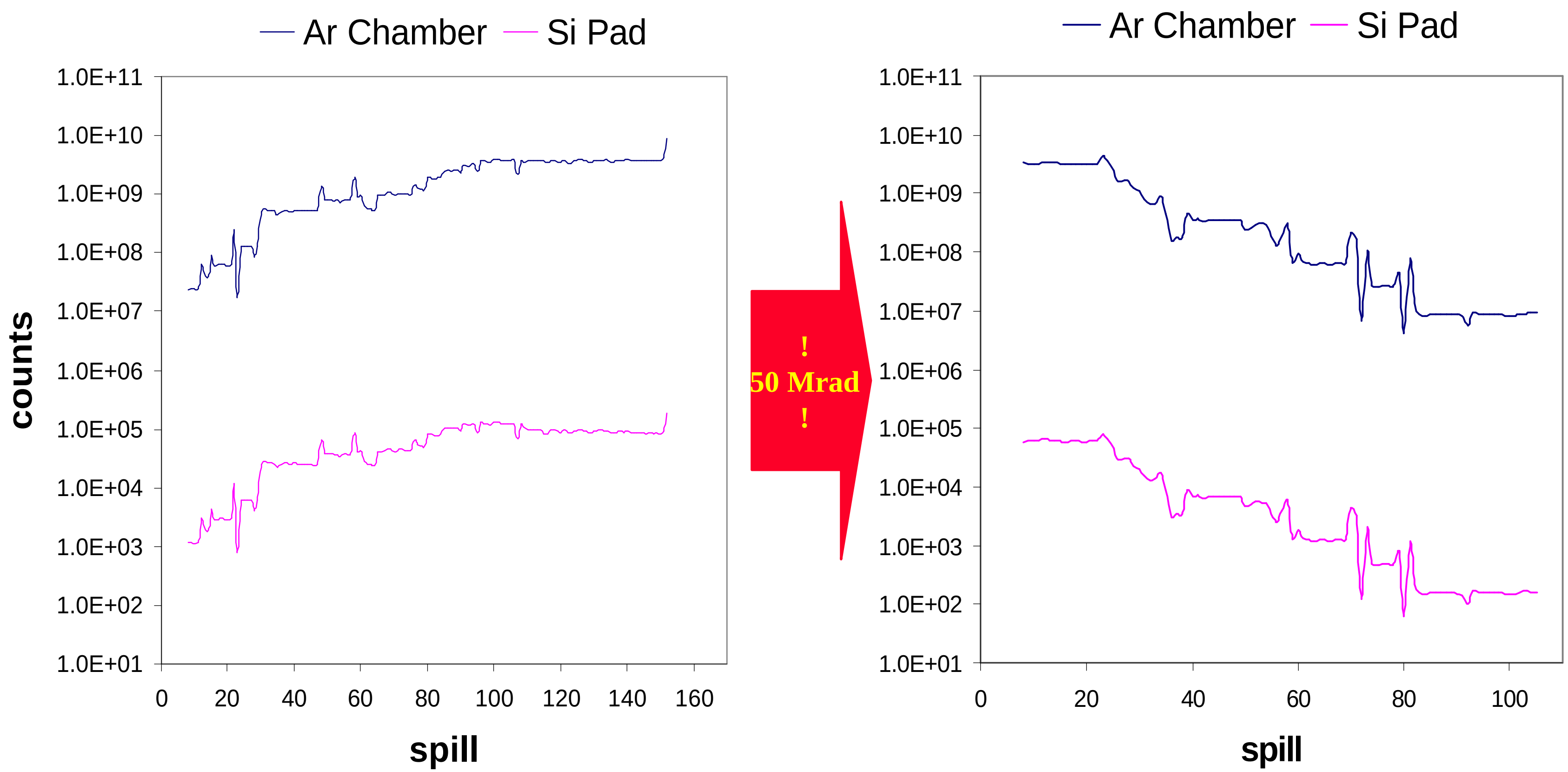




CERN SPS H4 Beam Line

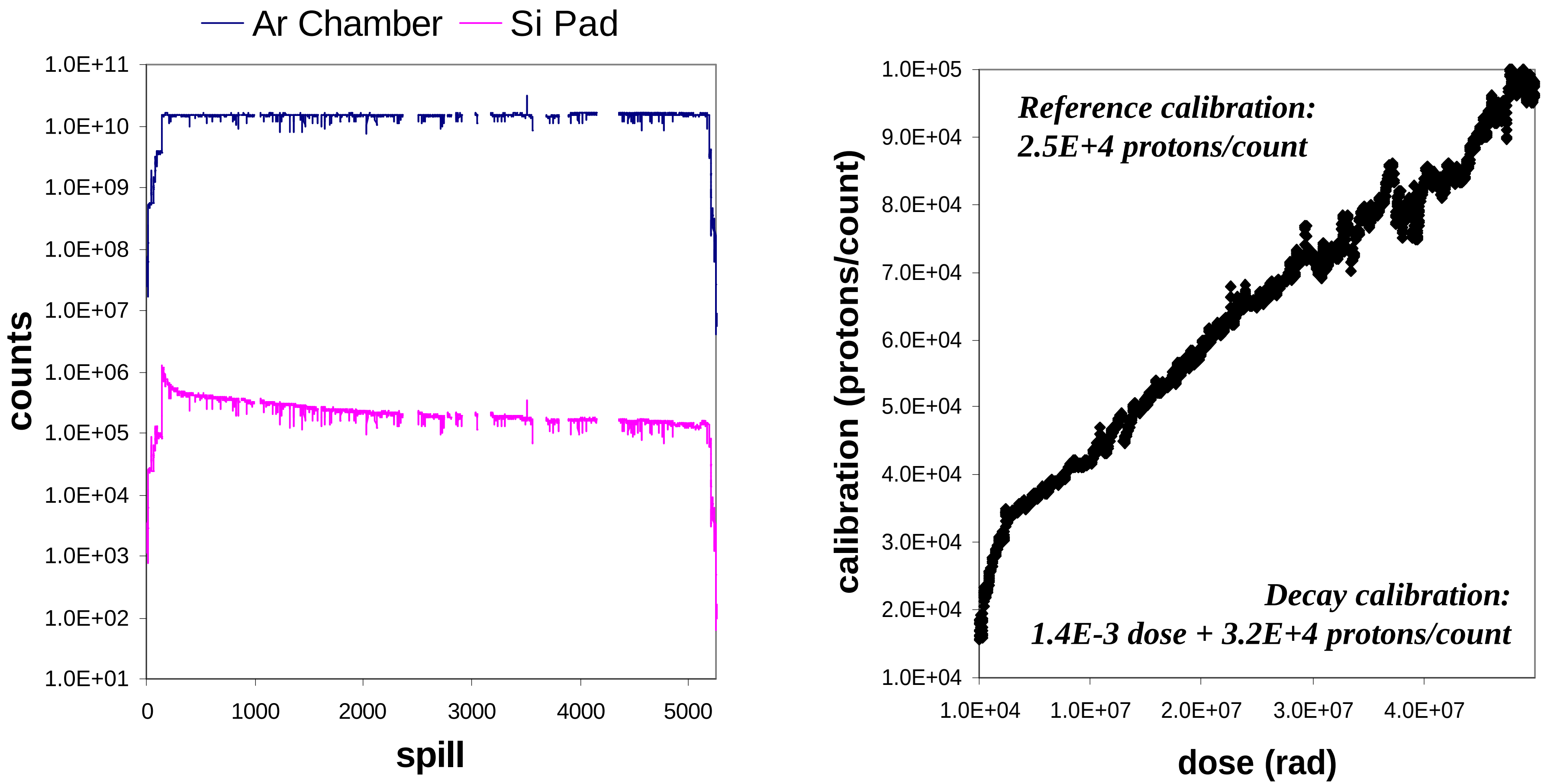
Using a simple scheme we were able to precisely measure the position and the intensity of the CERN SPS proton beam

Before and After Irradiation ...



The Si pad is perfectly functional after a dose of 50 Mrad and provides relative measurements over more than three oders of magnitude of beam intensity

... in Between



Absolute measurements of beam intensity are affected by radiation damage. However a nice linear behaviour is observed

Conclusions

- **Cryogenic cooling dramatically improves radiation hardness of silicon detectors**
  - A universal optimal temperature of 130 K is found for the Lazarus effect. At this temperature, after irradiating a 400 μm thick Si detector with $1 \cdot 10^{15}$ n/cm^2, a m.i.p. most probable signal of 27000 e^- is measured at 500 V. This corresponds to 80% CCE;
  - Segmented devices show a corresponding recovery of the position resolution when the CCE is restored;
- **Liquid nitrogen cooling can be made low-mass**
  - Foam isolation is sufficient for operation at 130 K;
- **Innovative concepts can take advantage of the properties of silicon at cryogenic temperature**
  - Solid-state ionization beam monitor can operate up to very high intensity (10^{10} protons per burst) and doses (50 Grad)