

# **Radiation Hard Cryogenic Silicon Detectors: The Lazarus Effect**

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

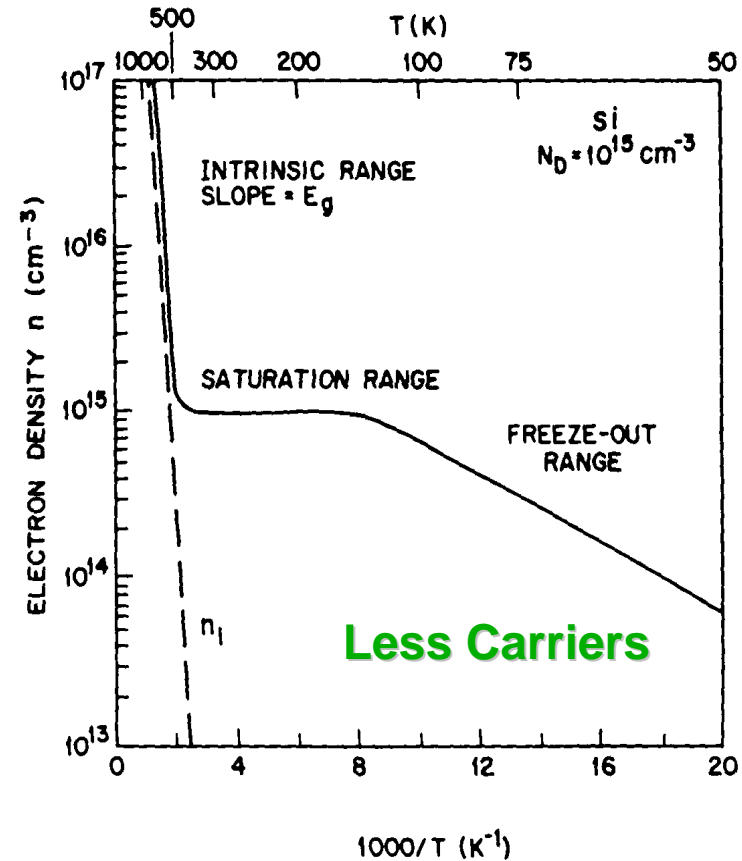
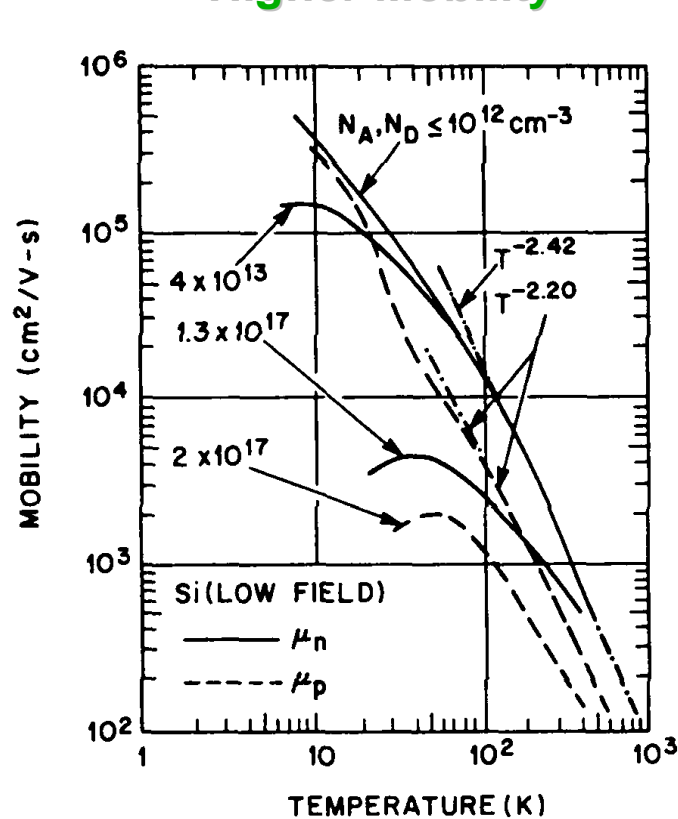
# Outline

- ◆ **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**

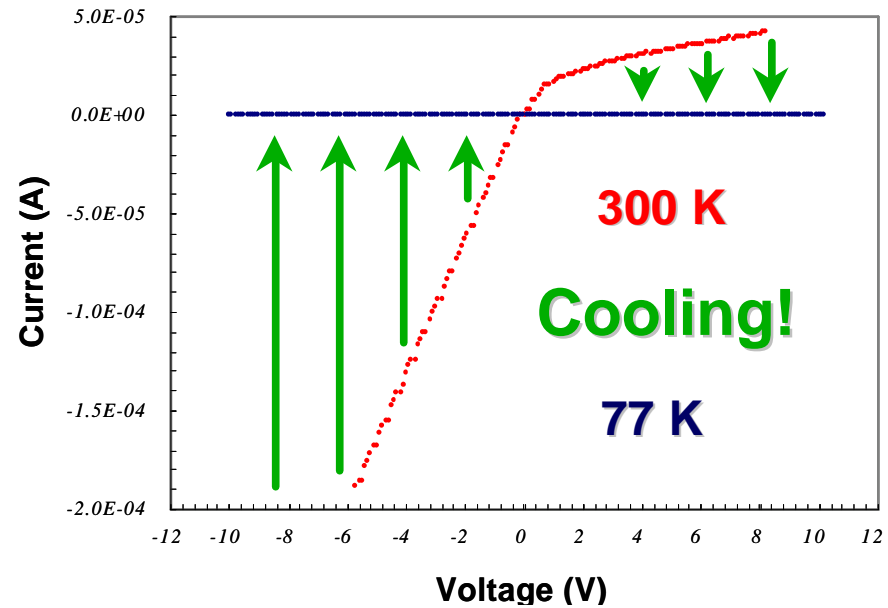
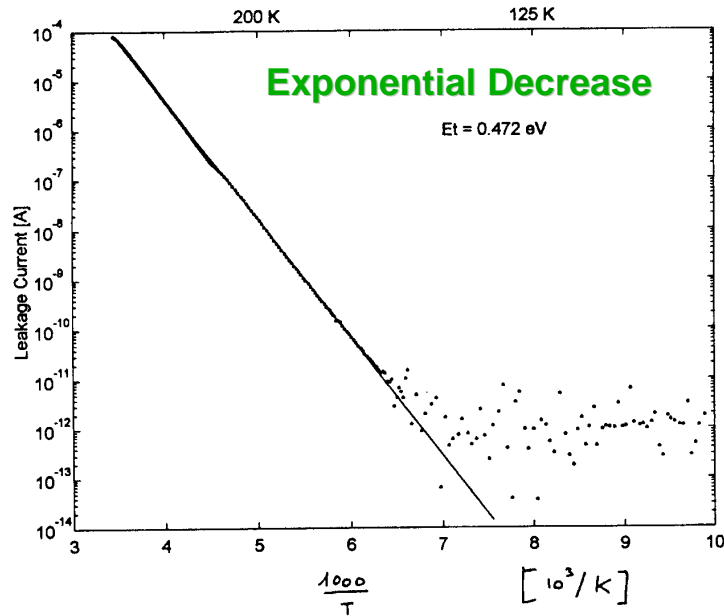
# Known facts about silicon detectors operated at cryogenic temperatures ...

# Properties of Silicon at Cryogenic Temperatures

## Higher Mobility



# Radiation Induced Leakage Current Reduction with Temperature

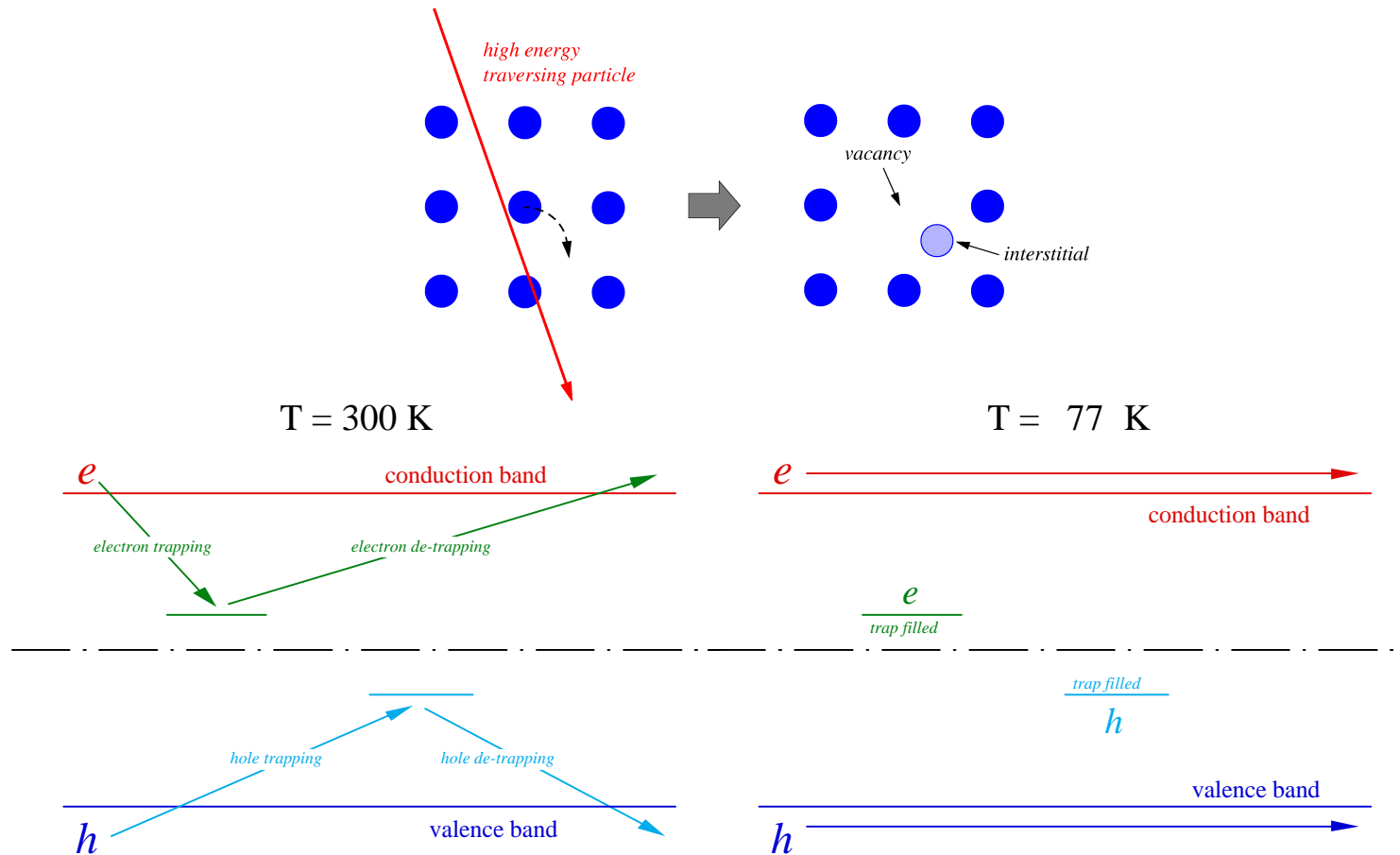


**At 77 K, detectors irradiated above  $5 \cdot 10^{14} \text{ n/cm}^2$  show less than 1 nA current in the bias range  $\pm 500 \text{ V}$**

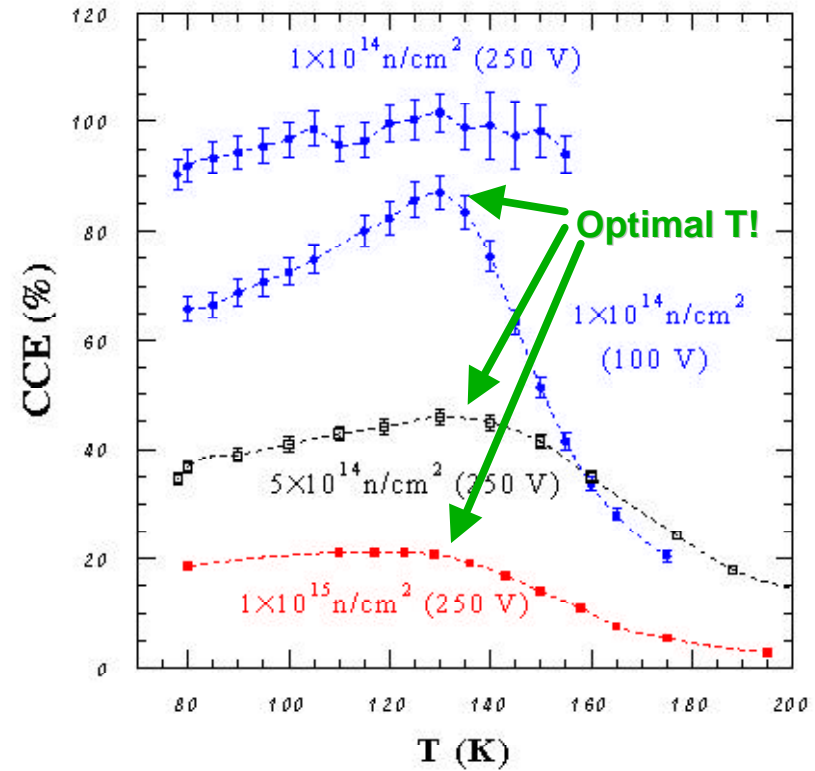
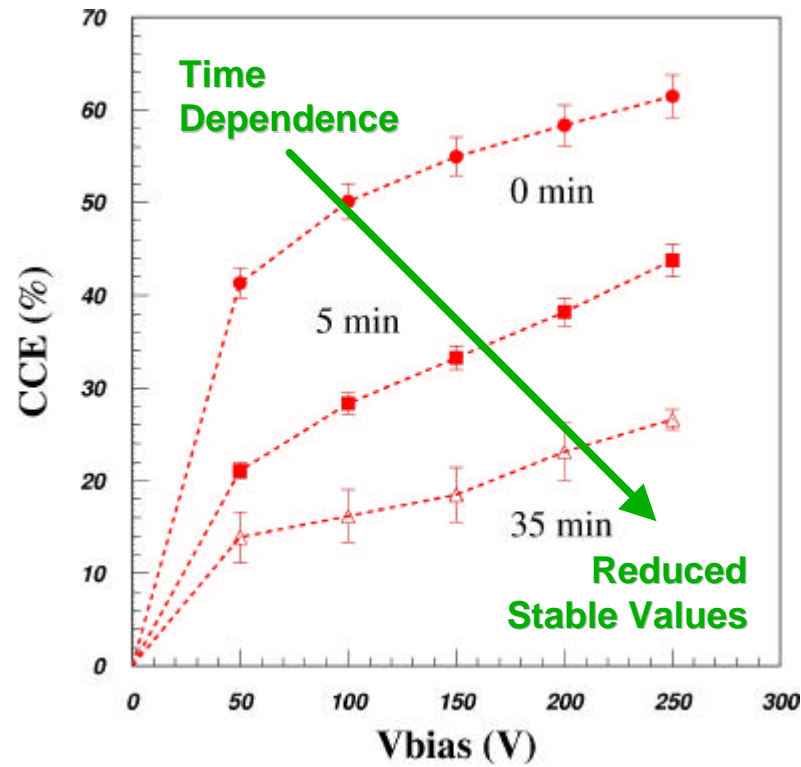
Is there anything else ?

...

# Electric Passivation of Radiation Induced Defects



# Conventional Operation



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

# The Lazarus Effect !

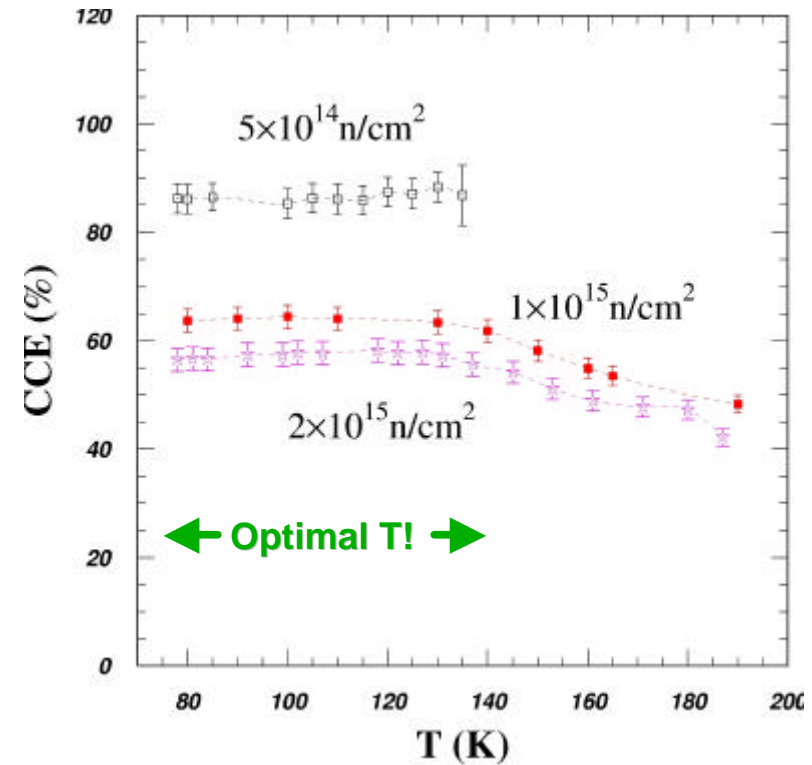
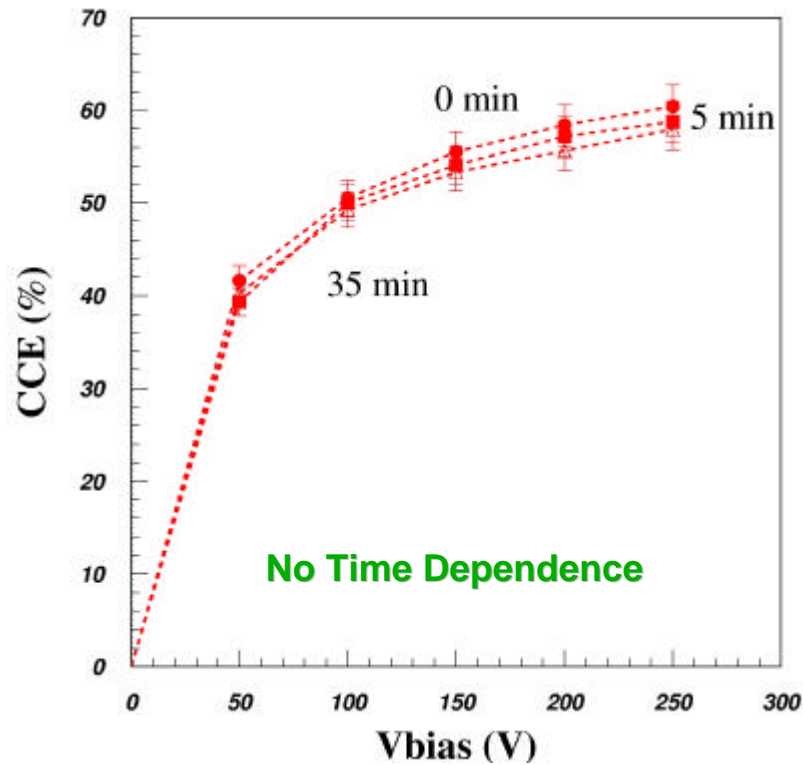


Is cryogenic silicon a new material ?

if yes ... what can we do with it ?

# Non-Conventional Operation

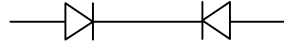
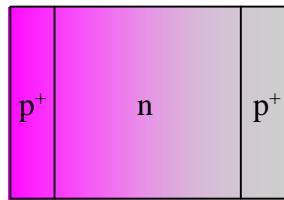
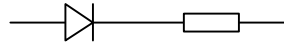
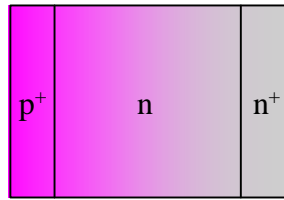
## Forward Bias



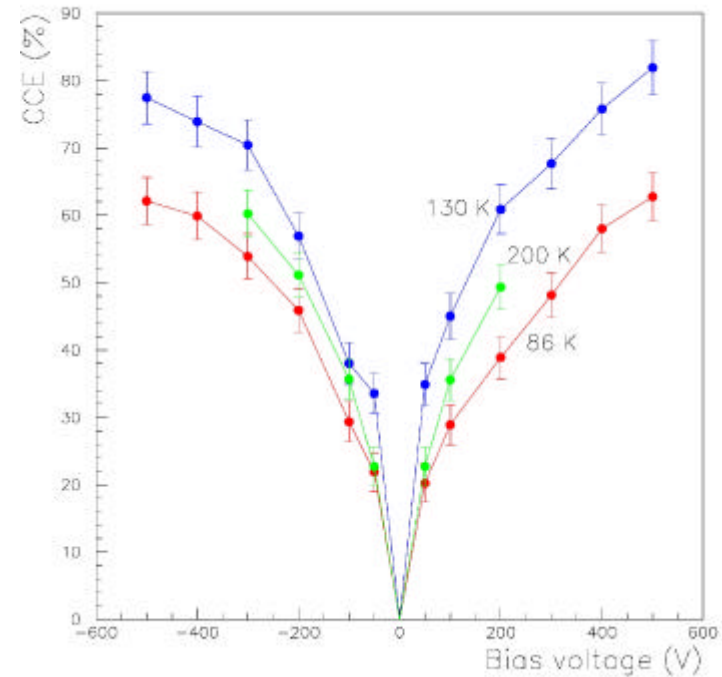
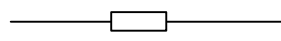
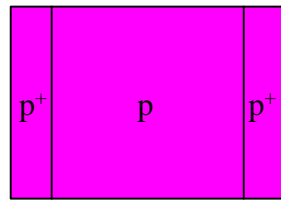
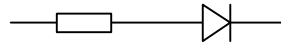
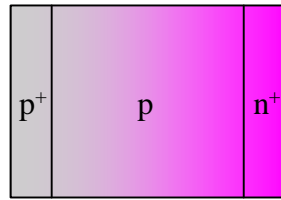
$$\left\{ 300 \text{ mm } 10^{15} \text{ n/cm}^2 + 130 \text{ K} + 250 \text{ V} = 25000 e^- \cdot 60\% = 15000 e^- \right\}$$

# “Double P” Detector

Before Irradiation



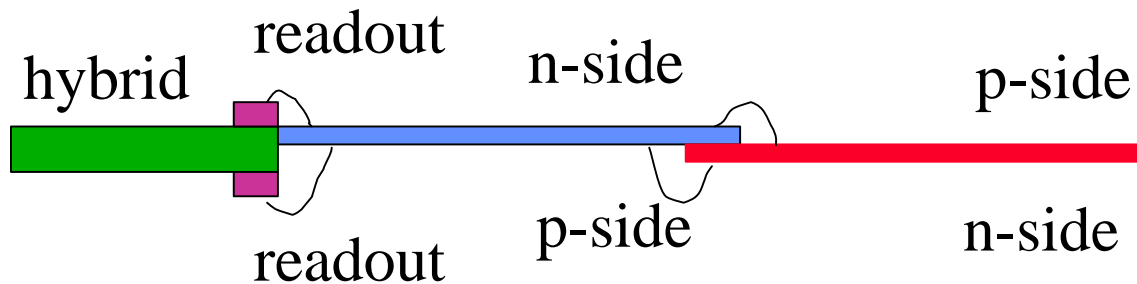
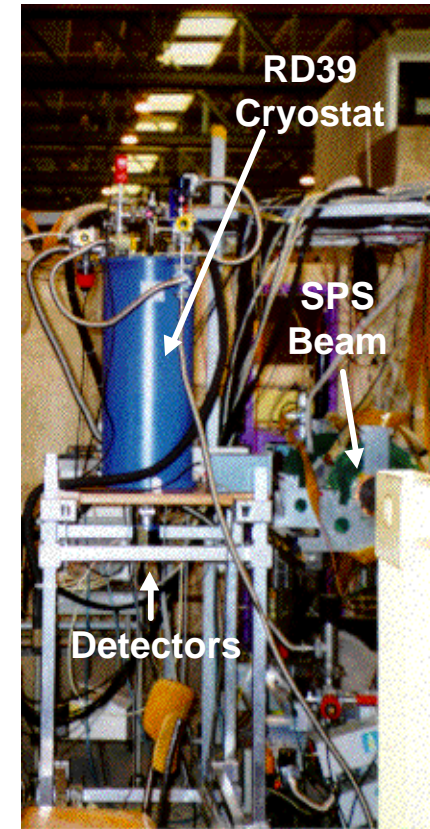
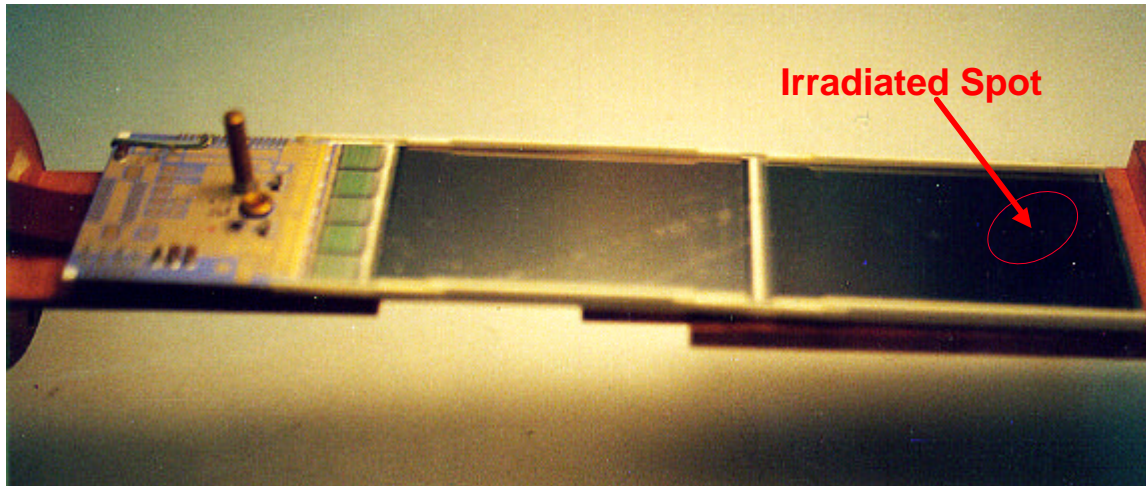
After Irradiation



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

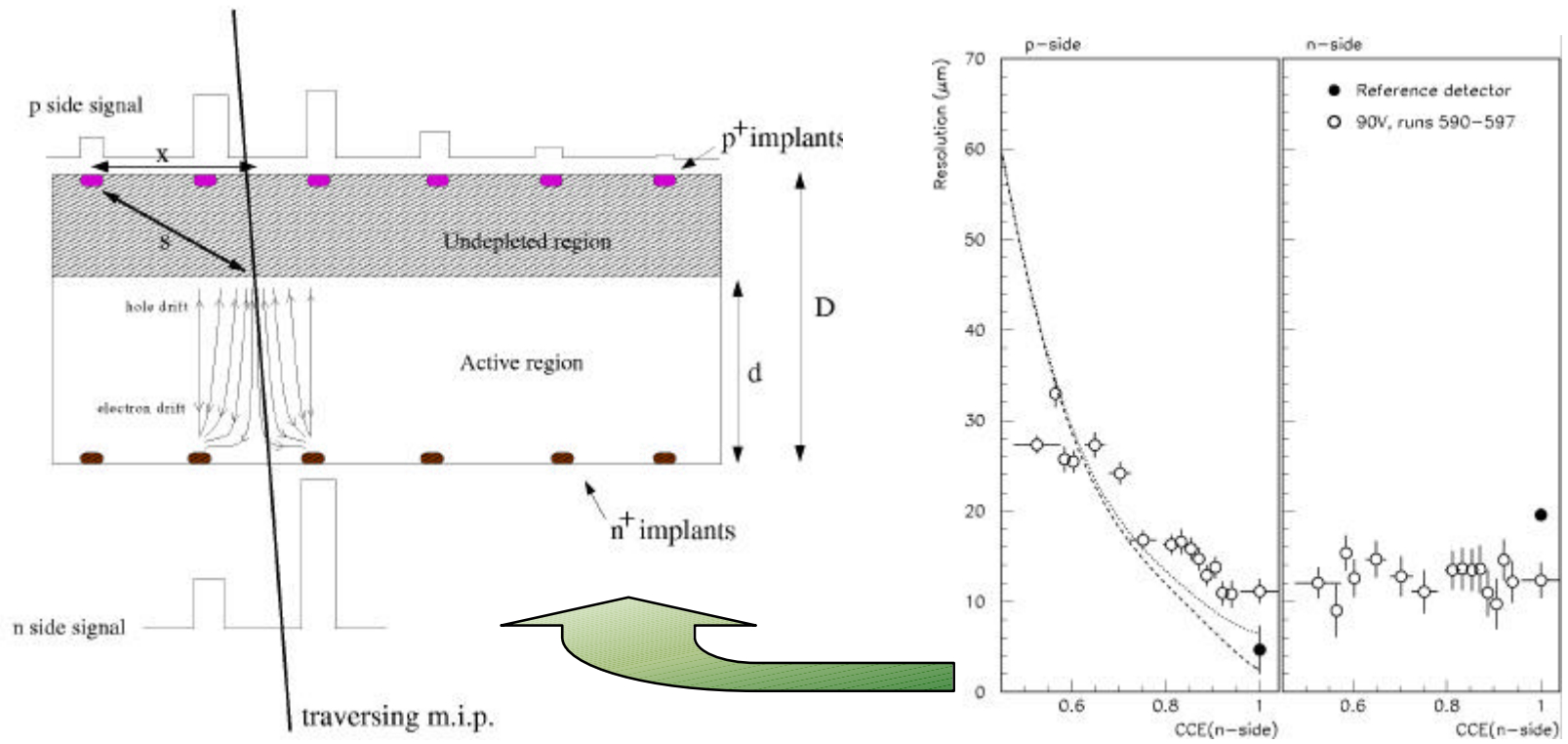
The charge is back, but what about position resolution ?

# The Cooled DELPHI Microstrip Detector Module



**3x12 cm<sup>2</sup>; 1280 Channels CMOS readout**

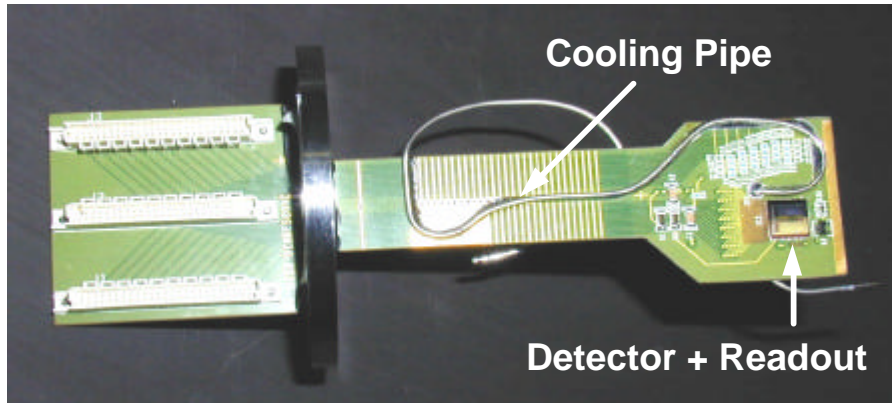
# Position Resolution



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

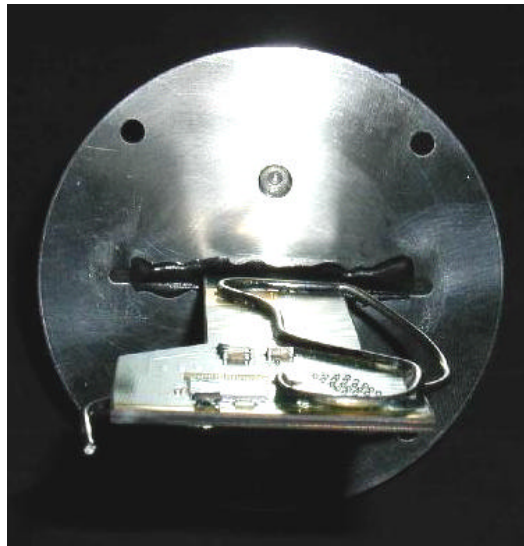
Is a “low mass” cryogenic system feasible ?

# Towards a “Low Mass” Cooling System

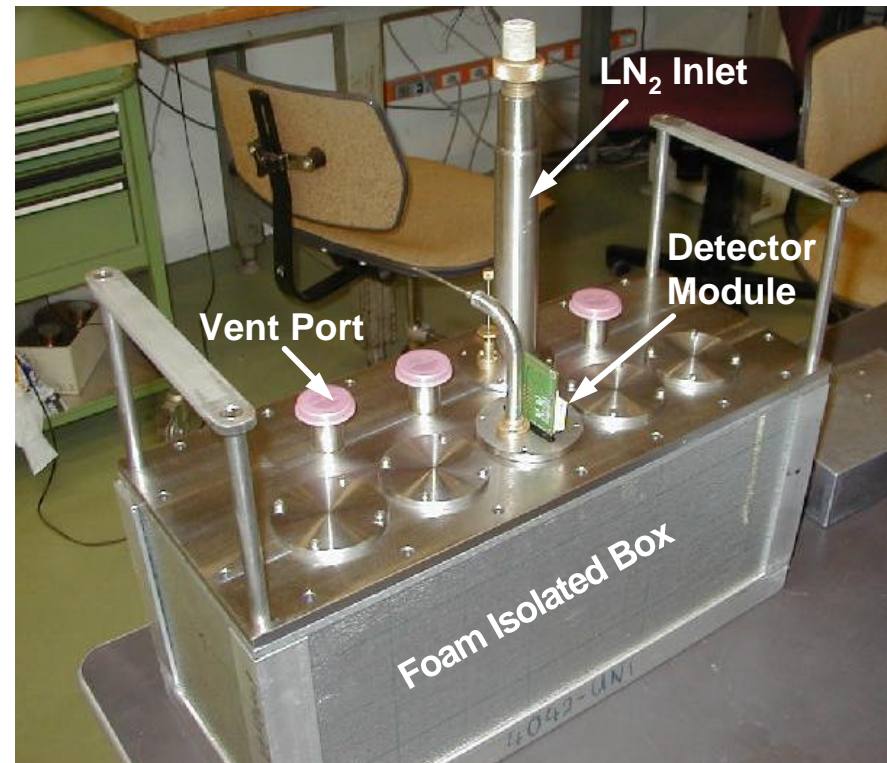


The cooling pipe is “low mass” (1 mm  $\varnothing$  100 mm thick)

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



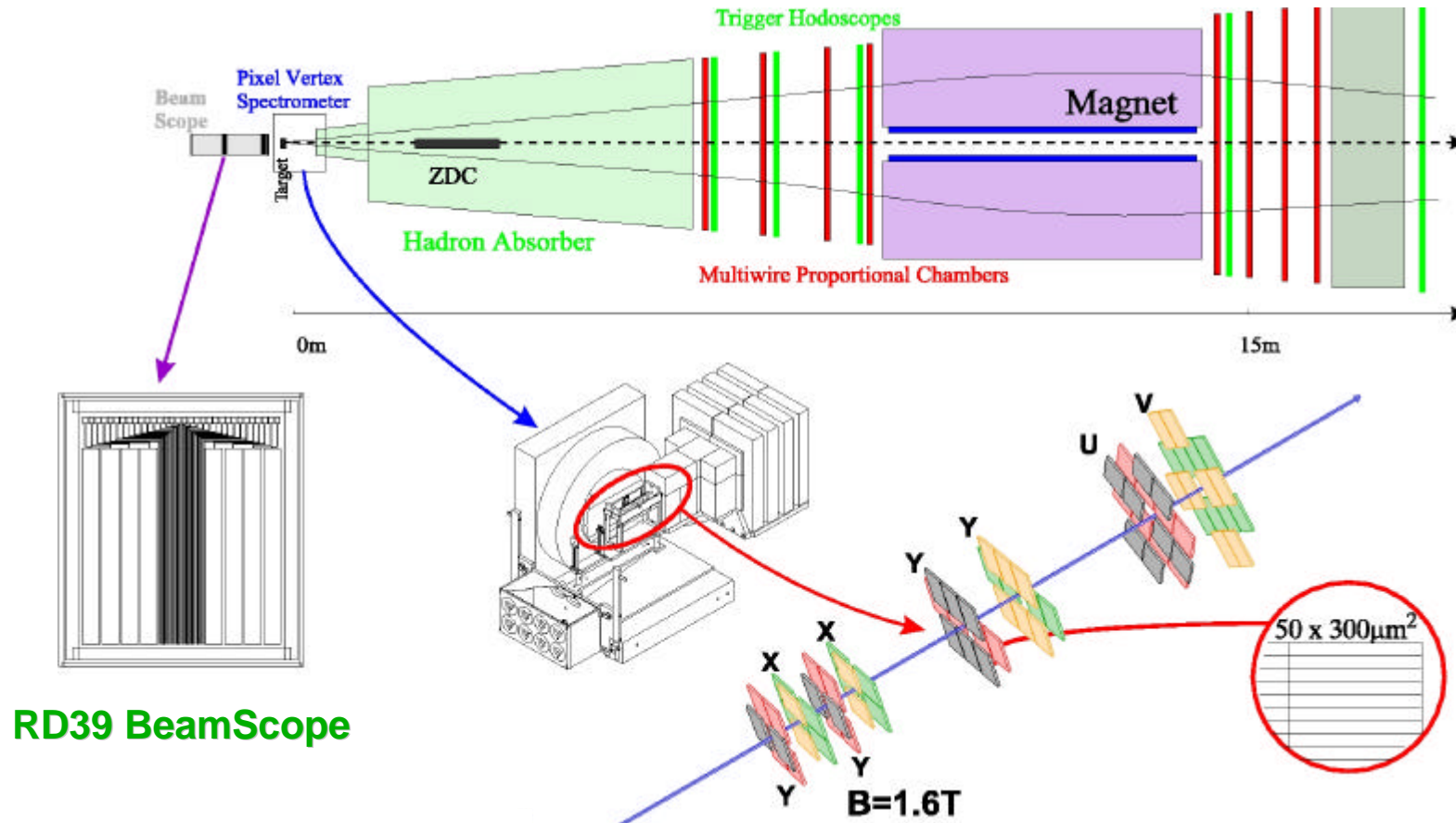
Liquid nitrogen is a very good coolant



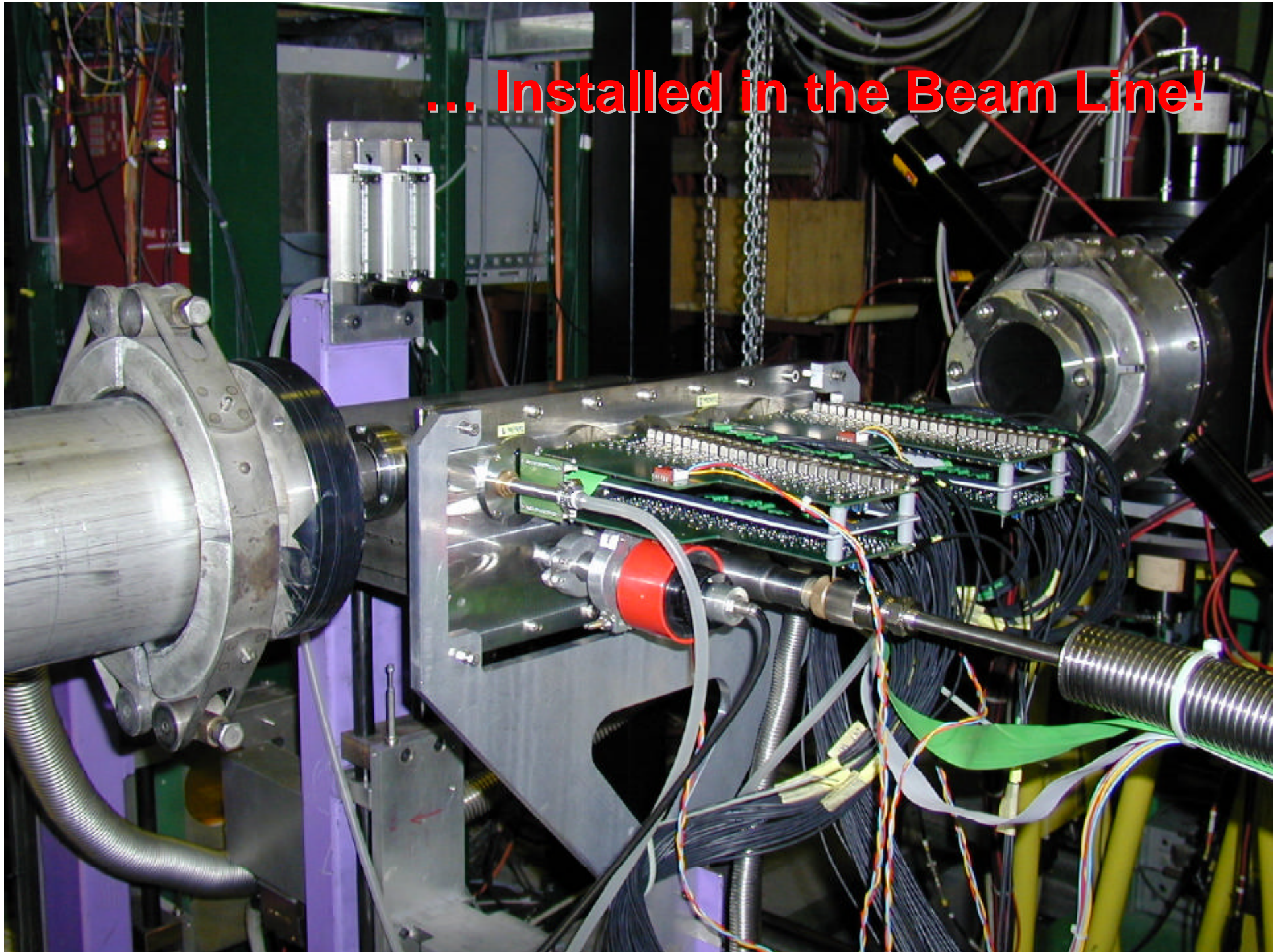
For 130 K operation, foam isolation (30 mm thick) plus dry gas atmosphere is sufficient

# The first application:

# The BeamScope for the CERN NA60 Experiment ...

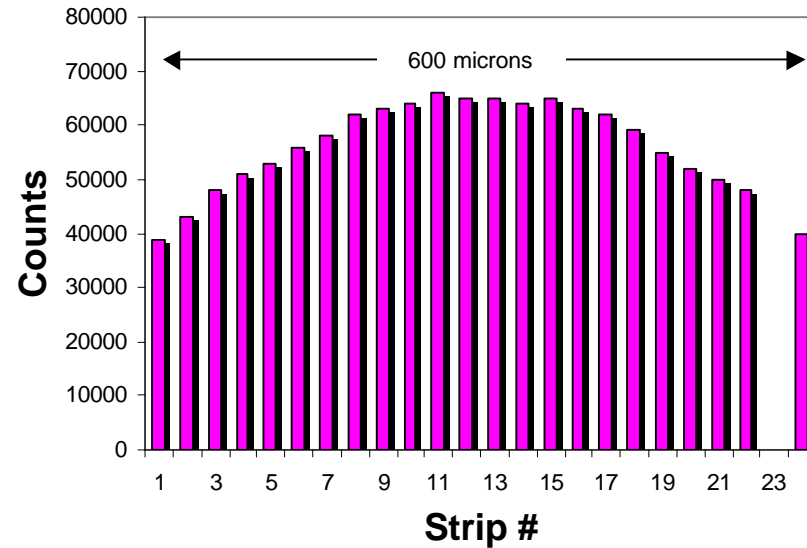
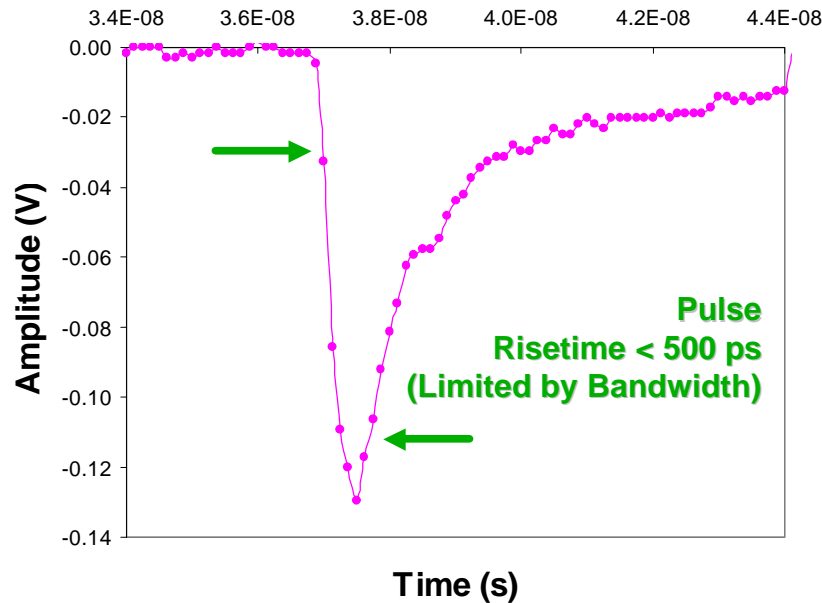


**... Installed in the Beam Line!**



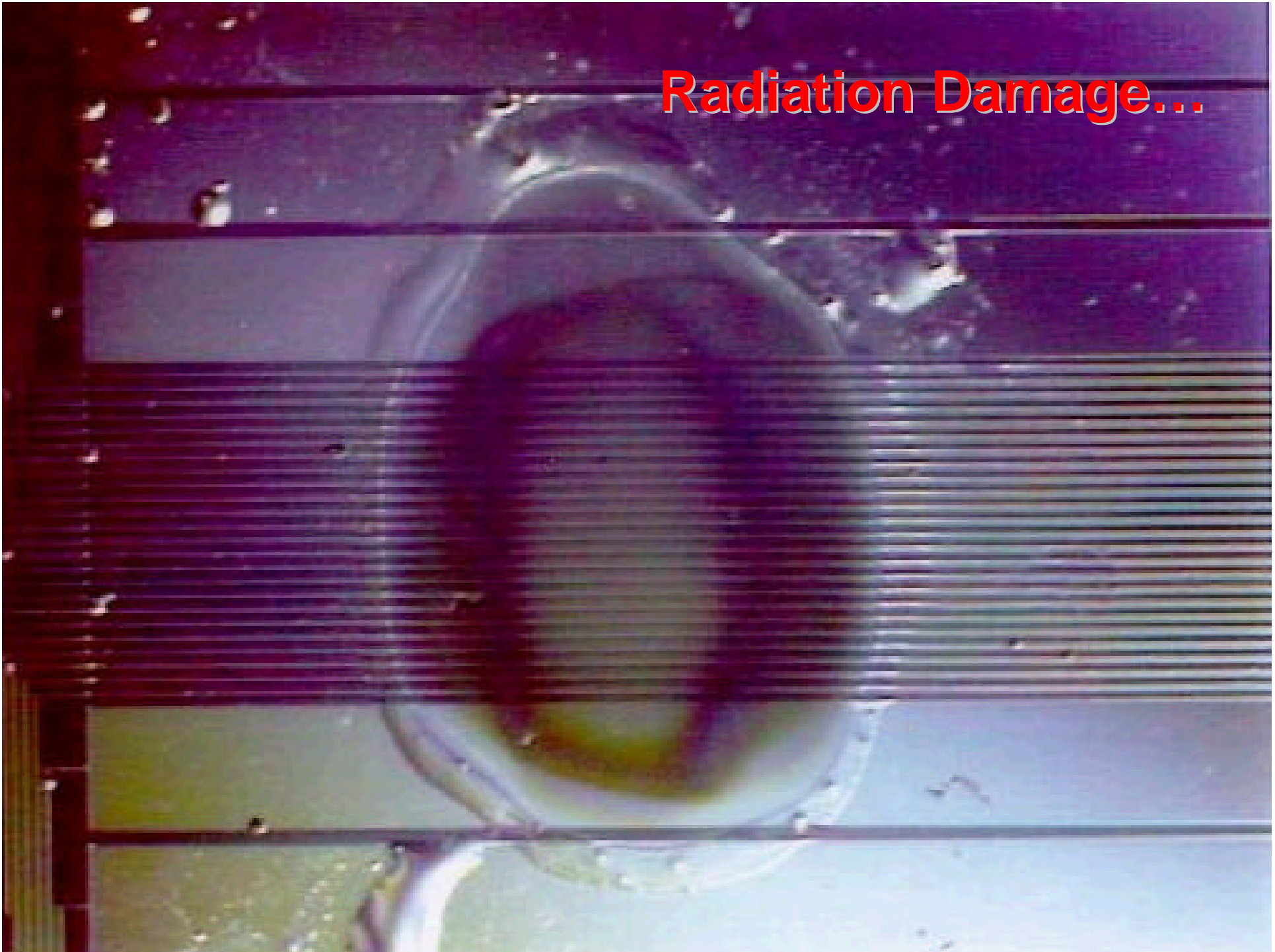
# The CERN SPS High Intensity Pb-Ion Beam as seen by the BeamScope

Using a strip pitch of 50  $\mu\text{m}$ , 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...**

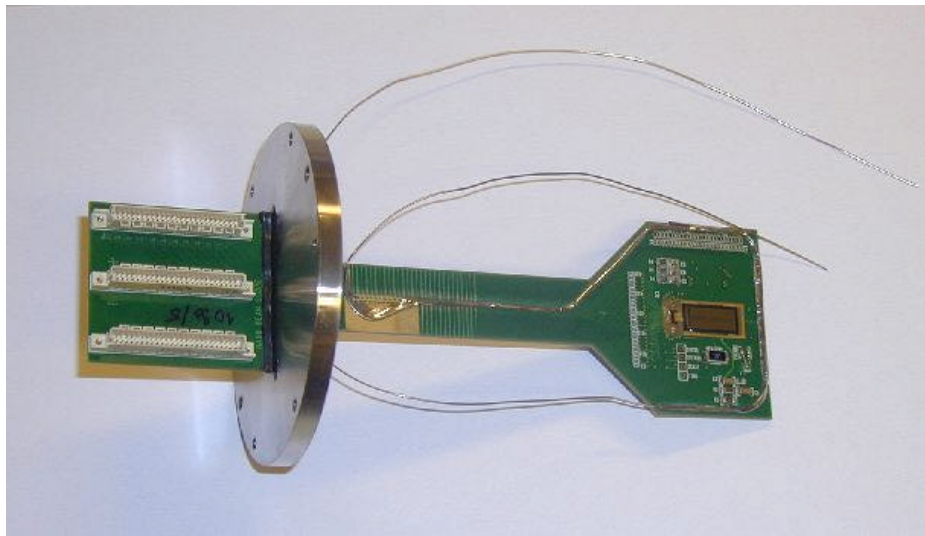
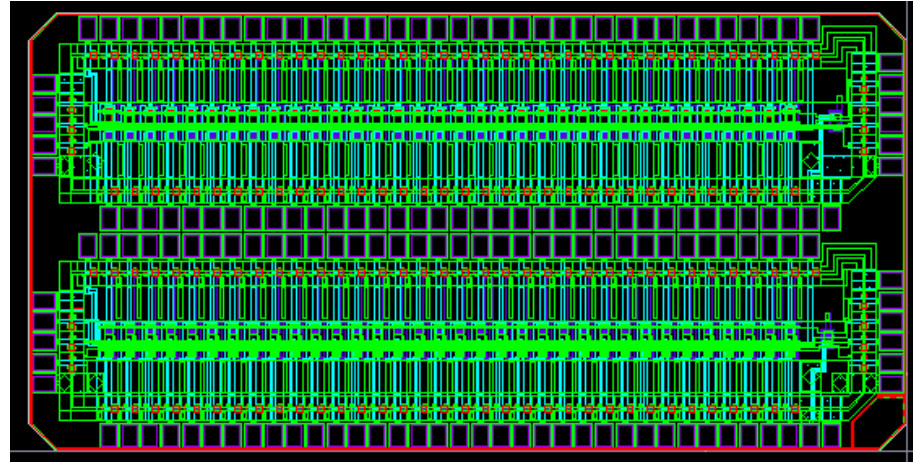


Which radiation hard  
readout electronics for the  
cold ?

# The Proton Beamscope

A new front-end chip by CERN  
EP-MIC group manufactured in  
0.25  $\mu\text{m}$  radiation-tolerant CMOS  
technology:

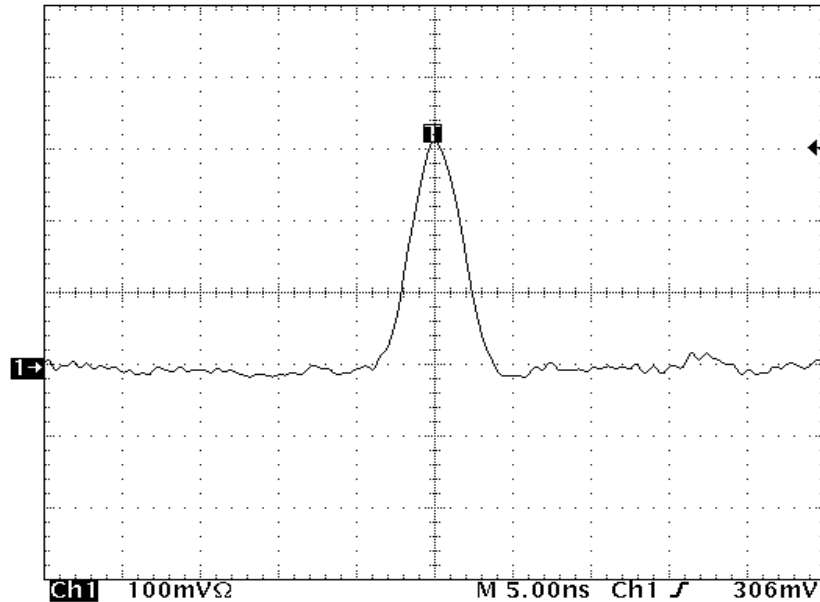
2  $\times$  4  $\text{mm}^2$ ; 32 channels  
peaking:  $\sim 3.6$  ns at 130 K  
good S/N down to 2500e  
power dissipation:  $\sim 300$  mW



Improved module:

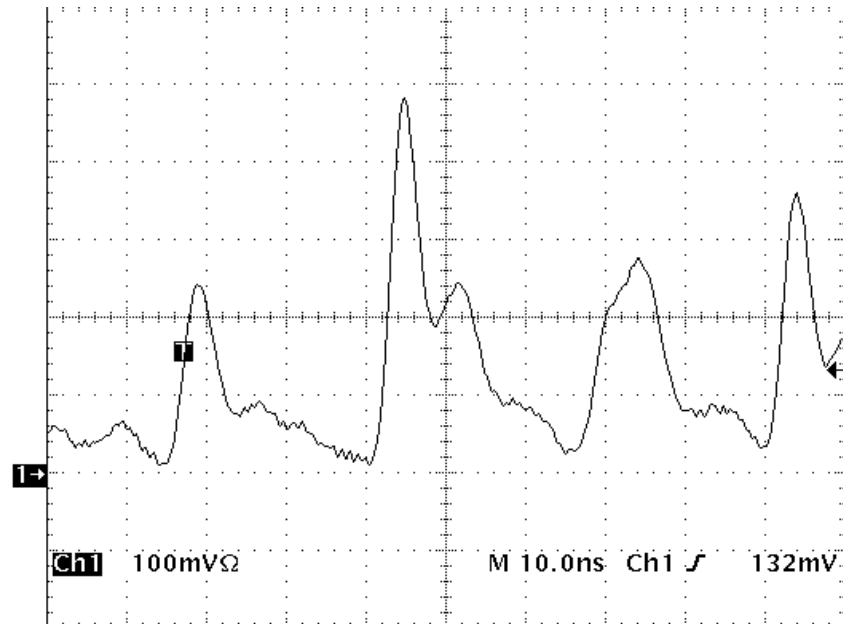
optimized microstrips  
new PCB design  
0.5 mm diameter pipes

# How Protons Look Like...



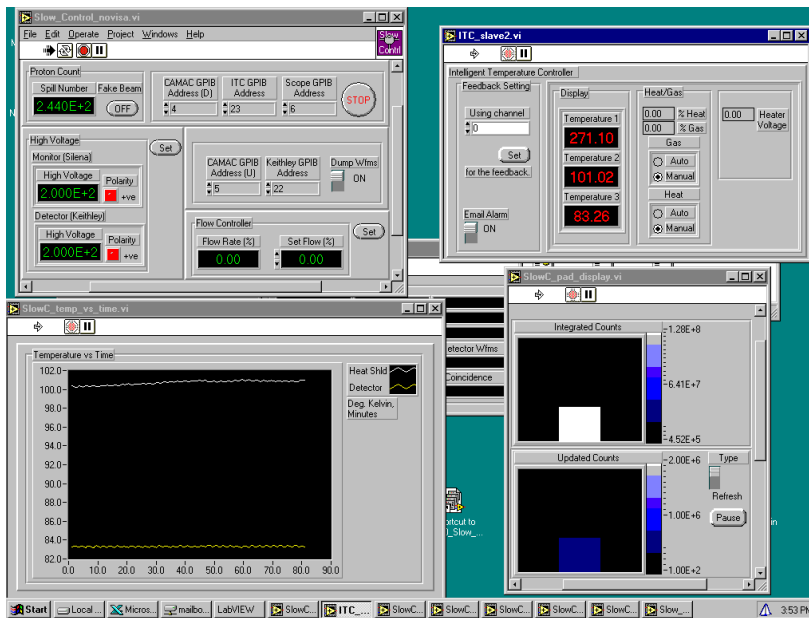
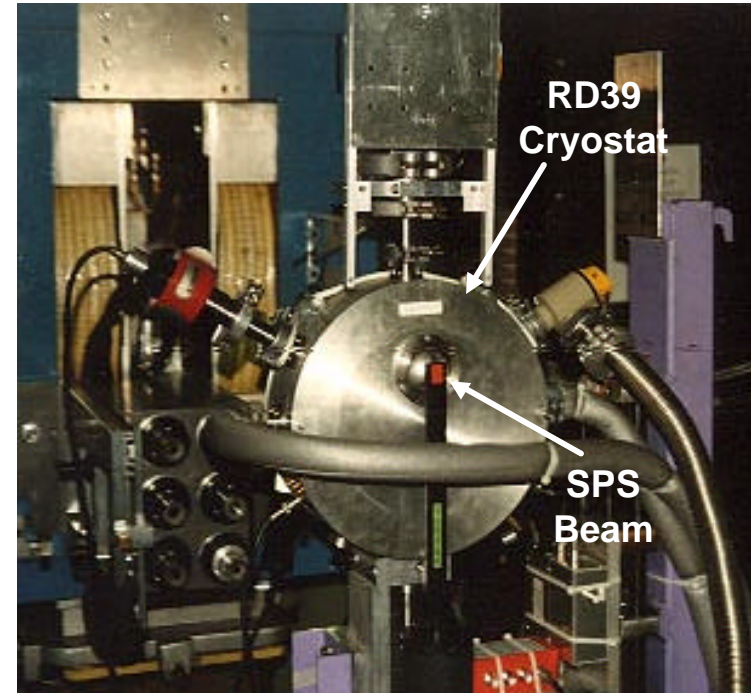
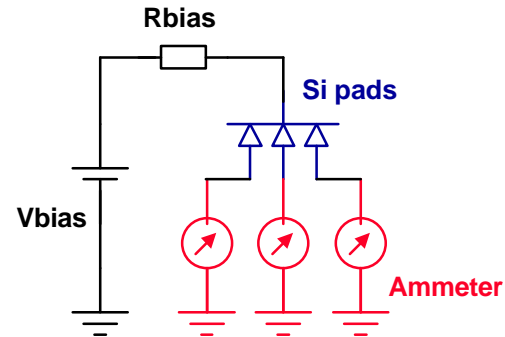
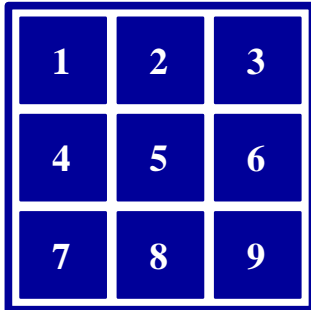
Single proton signal as seen by a fast digital oscilloscope after front-end chip and shaping stage. Extremely fast signal with good S/N

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



# Innovative concepts:

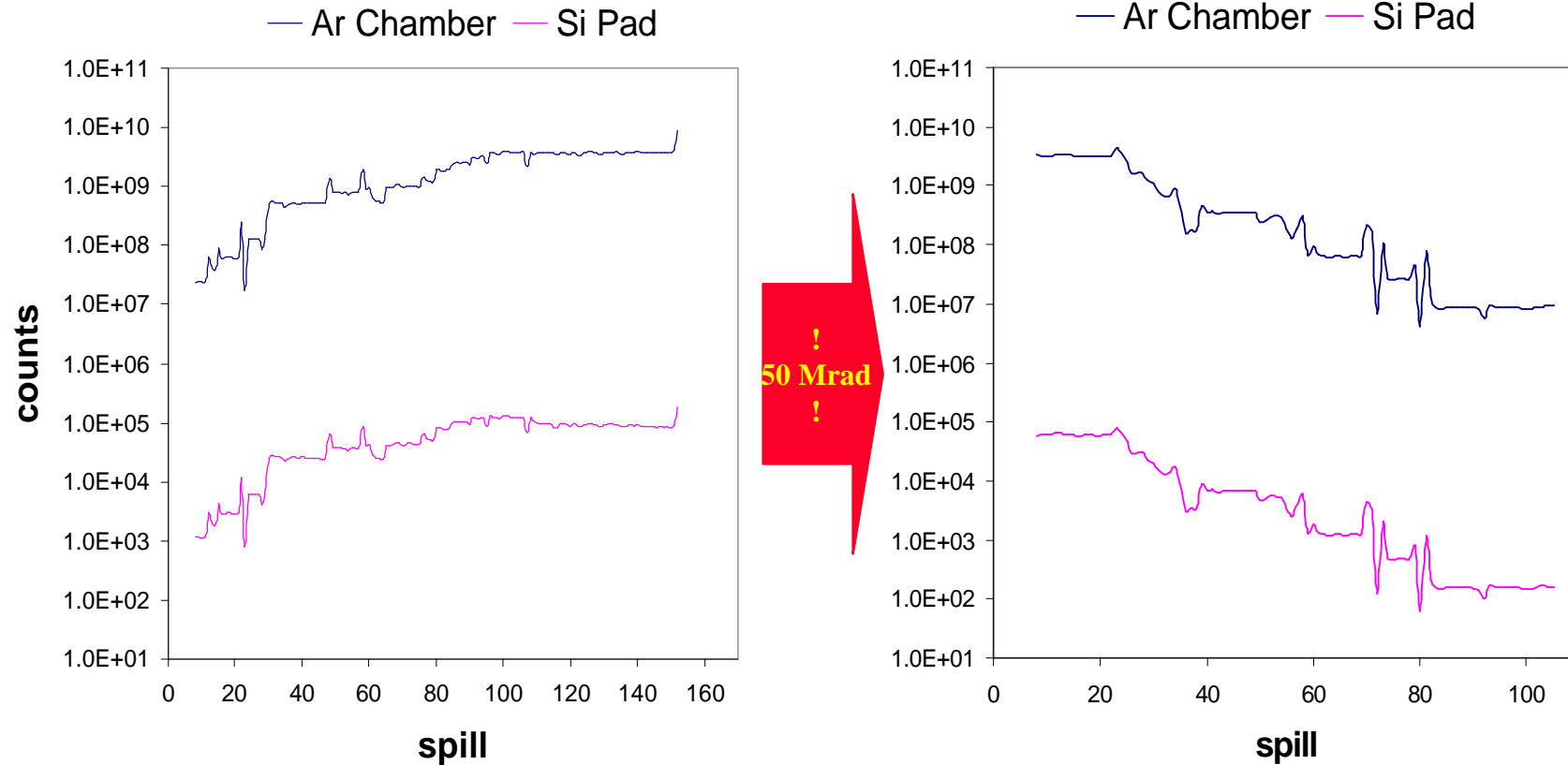
# Solid-State Ionization Beam Monitor



CERN SPS H4 Beam Line

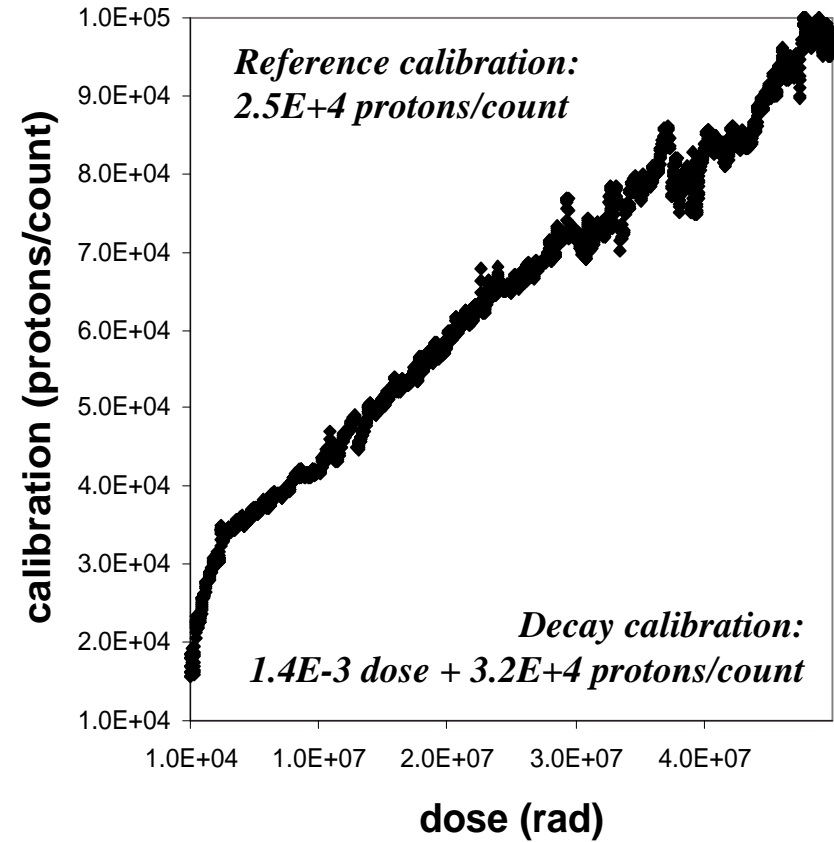
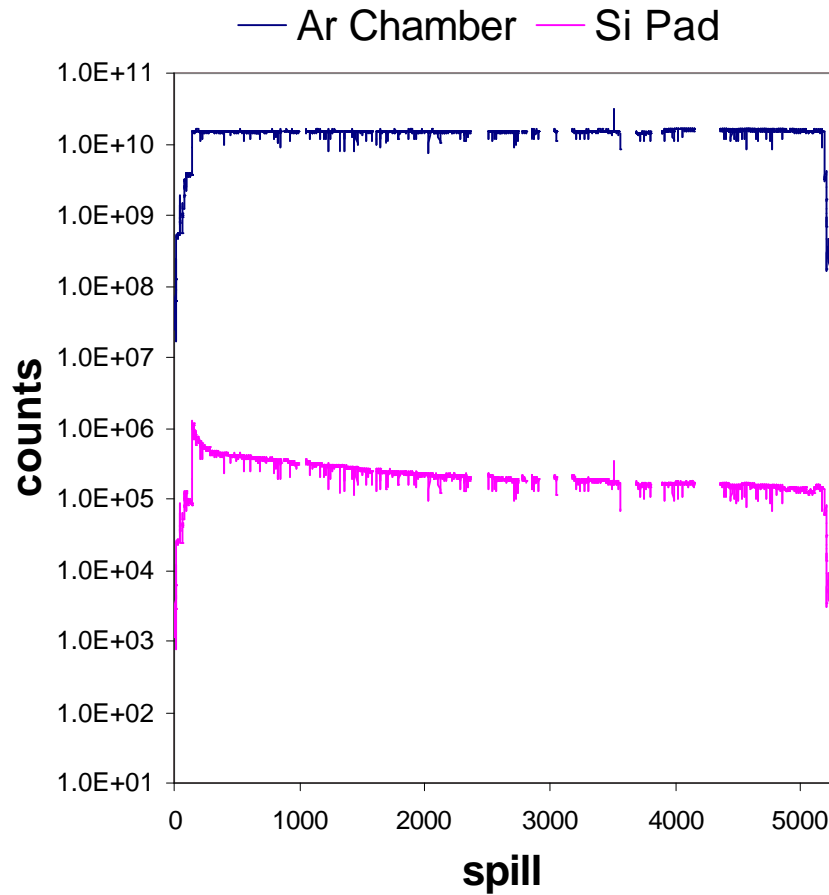
Using a simple scheme we were able to precisely measure the position and the intensity of the CERN SPS proton beam

# Before and After Irradiation ...



**The Si pad is perfectly functional after a dose of 50 Mrad and provides relative measurements over more than three orders 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 mm thick Si detector with  $1 \cdot 10^{15}$  n/cm<sup>2</sup>, a m.i.p. most probable signal of 27000 e<sup>-</sup> 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)