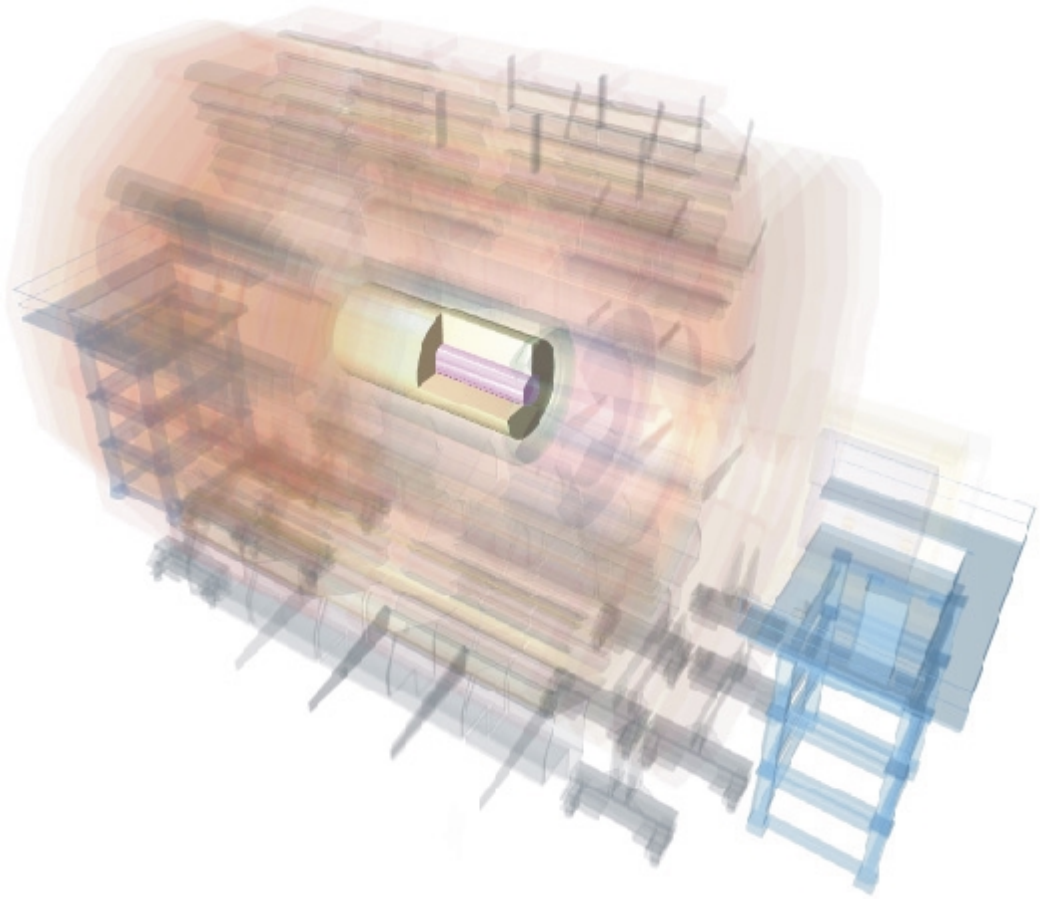
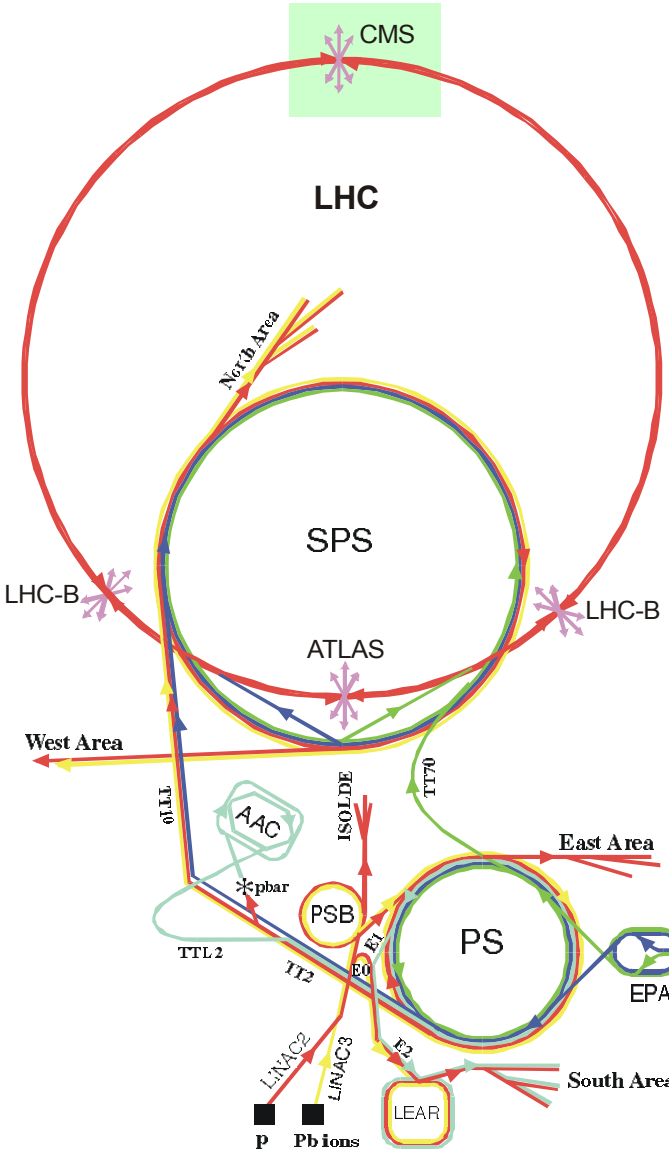
The CMS Silicon Strip Tracker
and its Electronic Readout



Markus Friedl · Dissertation · May 2001

Introduction

LHC — Large Hadron Collider: future high energy physics accelerator at CERN (starts 2006)

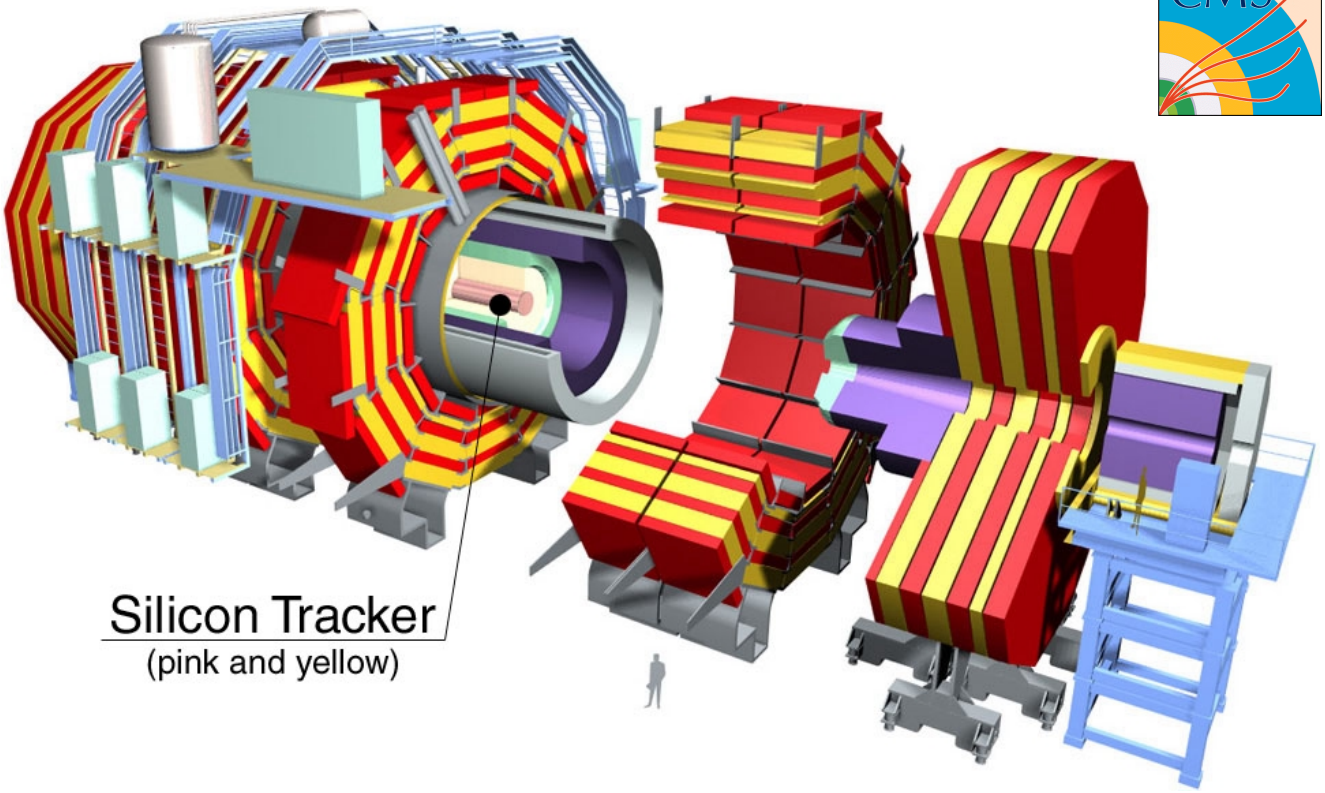


electrons
positrons
protons
antiprotons
Pb ions

Aim — Measure new particles and their properties to verify the “Standard Model” (e.g. Higgs)

Introduction

CMS — Compact Muon Solenoid: One of four collision detectors at LHC



Tracker — Silicon strip and pixel detectors (206m^2)

384 scientists from 42 institutes participate

Austria — Insistute of High Energy Physics (HEPHY)
Austrian Academy of Sciences
Nikolsdorfergasse 18
A-1050 Vienna

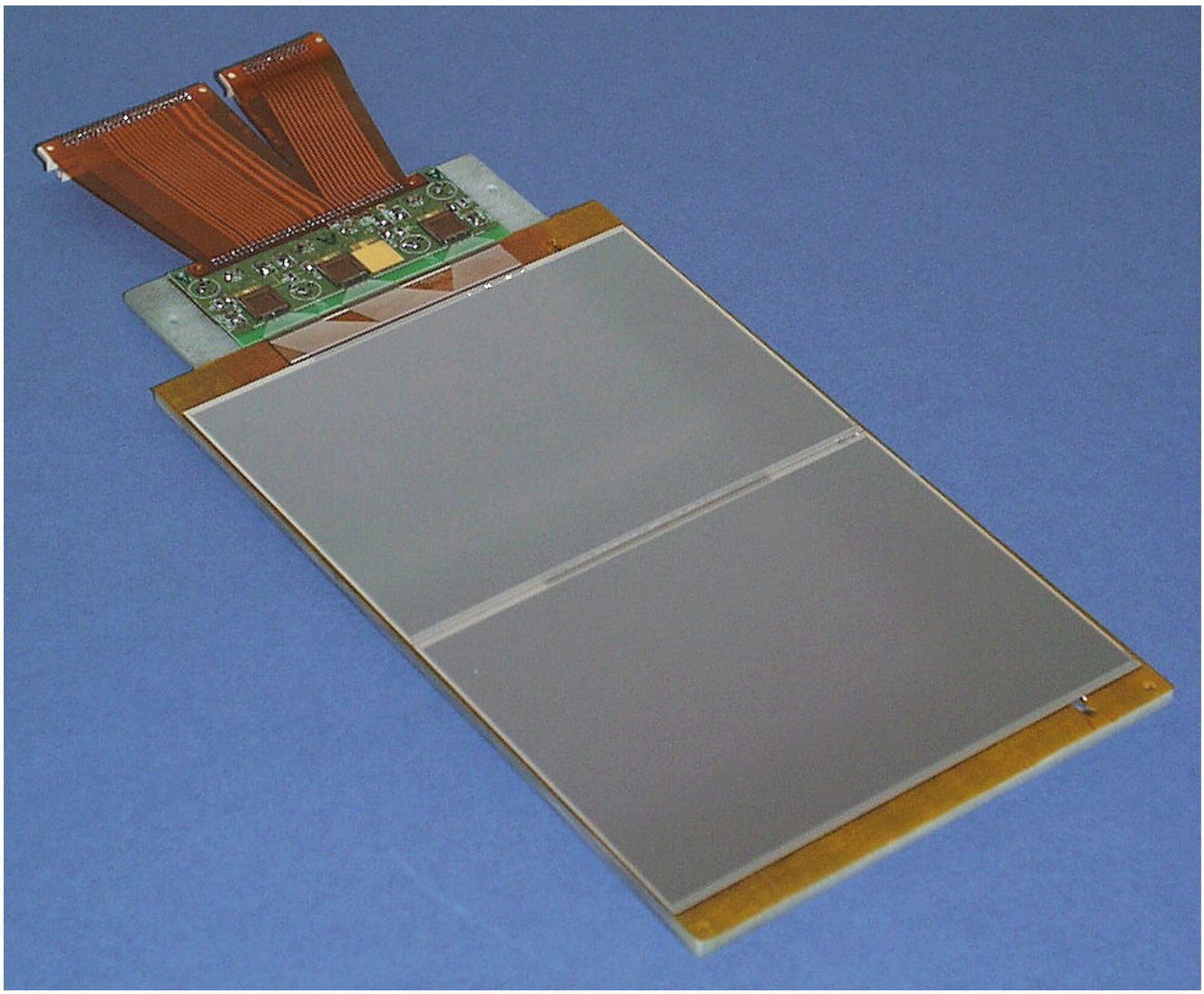
Thesis Contents

LHC/CMS	Introduction to future particle accelerator and collider experiment at CERN ✓
Silicon detectors	General principle and readout amplifiers including detector model and simulations (published in Nucl. Instr. Meth. A461 (2001) 192-196)
CMS Silicon Tracker	Details about configuration and readout electronics
My research	Construction and tests of detector modules ☞ and readout components
	Irradiation of detectors and electronics ☞
	Analog optical link evaluation
	Magnetic field tests
	ADC frequency response measurements

Silicon Detector Module Tests

CMS Silicon Tracker

Prototype detector module with three APV25 front-end readout chips (HEPHY Vienna)



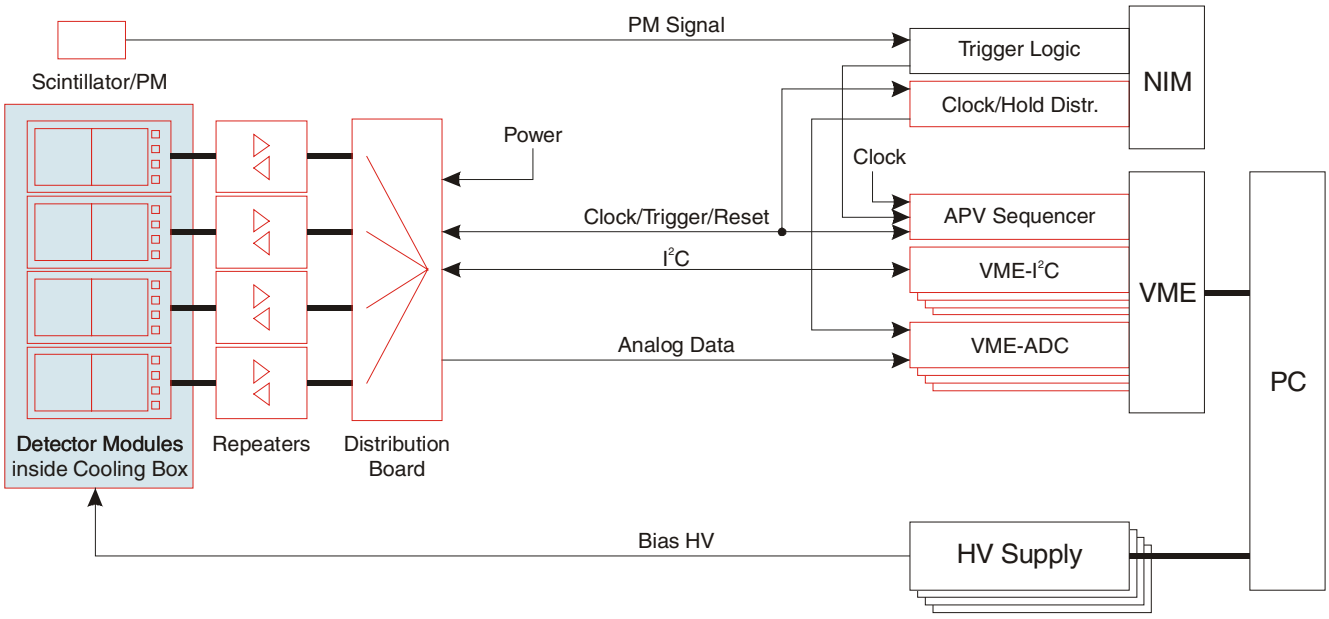
Tests

Characterized in particle beam together with other modules

System Overview

HEPHY setup

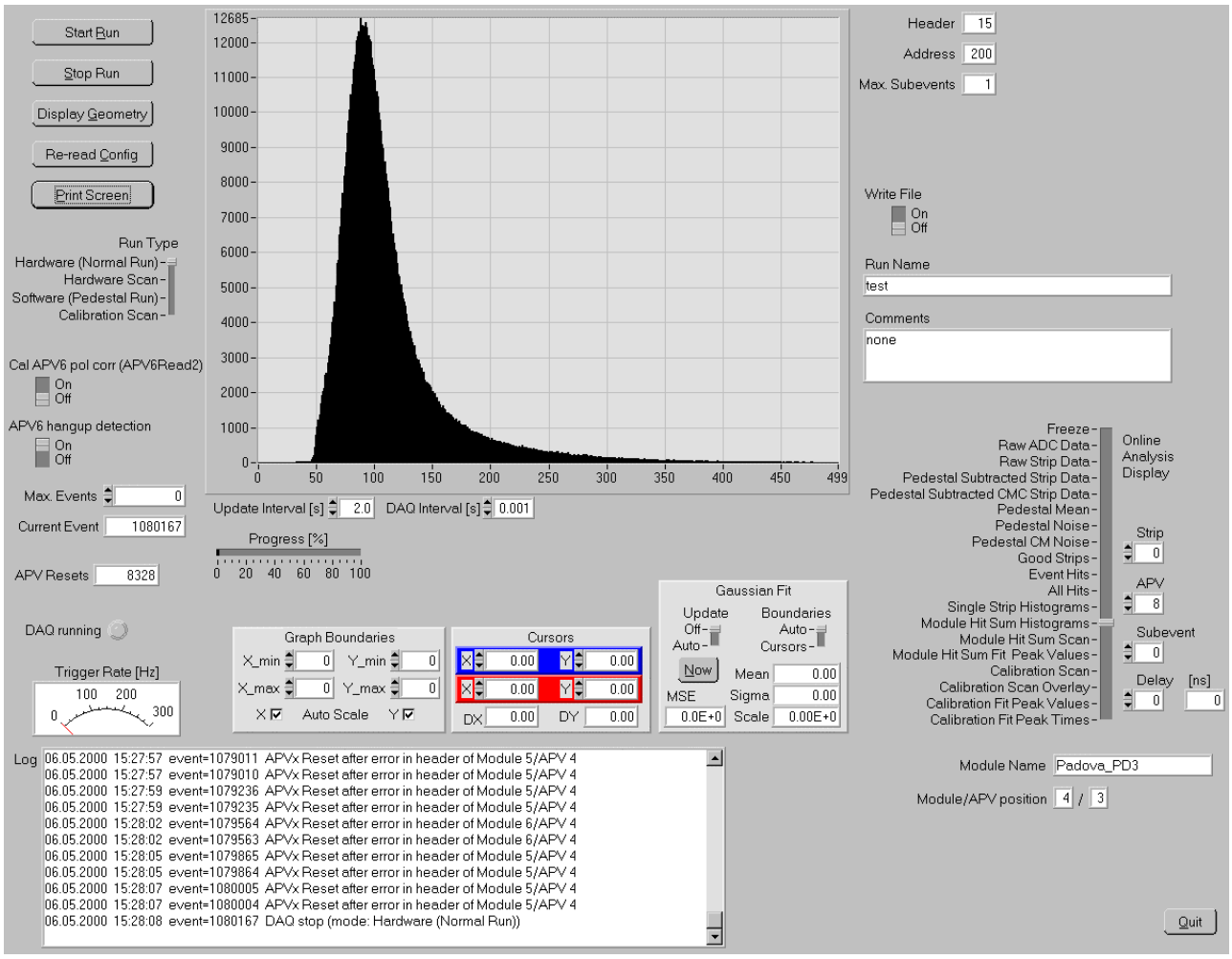
- Complete APV readout hardware
- Cooling box for detector operation at –10°C
- VME-based back-end system
- PC-controlled data acquisition



- Components shown in red are self-made

System Overview

Software — Powerful control and readout system (self-made)



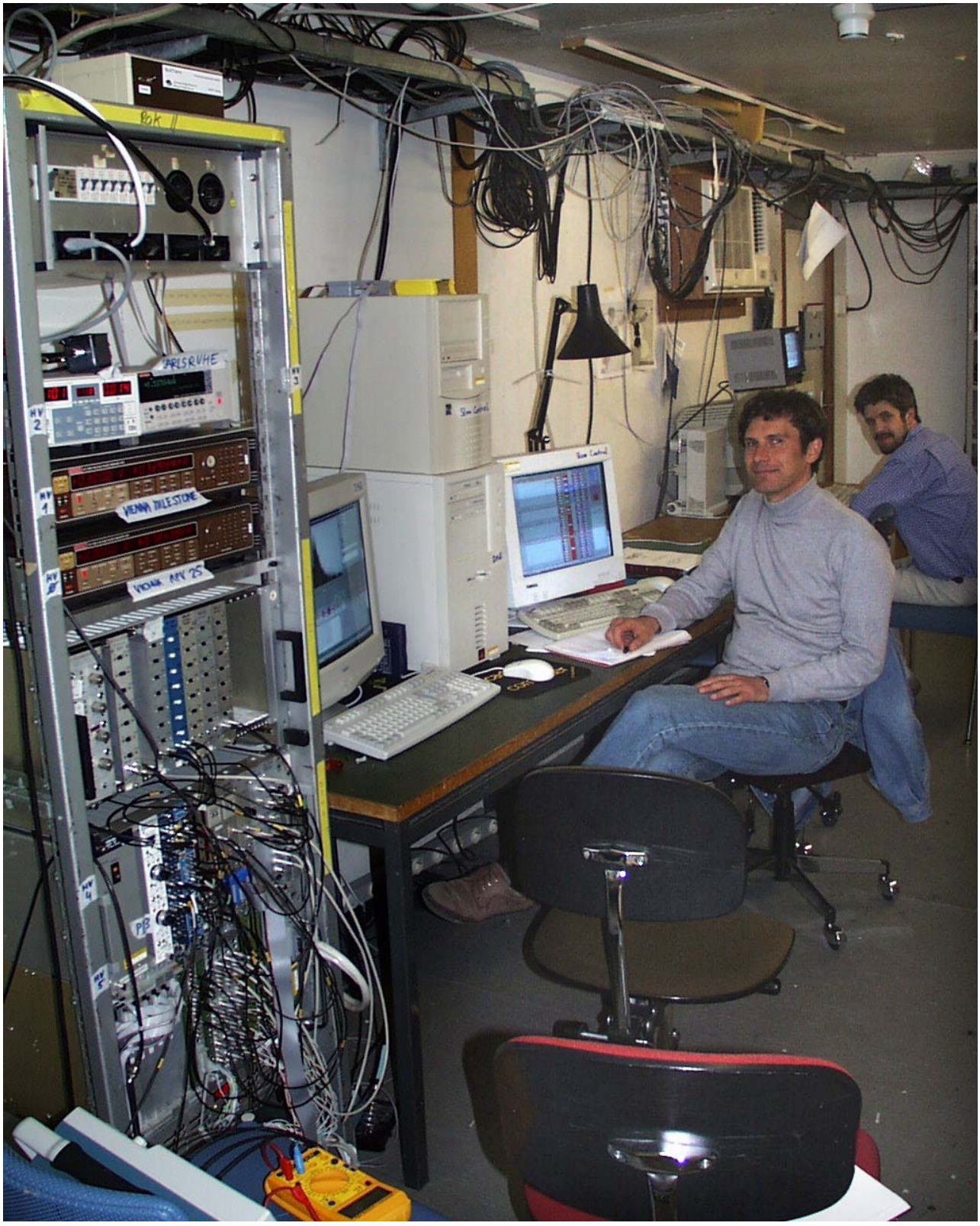
Screenshot — Data acquisition software displaying Landau signal distribution (online analysis)

Slow Control — Second PC for temperature and HV control/monitoring

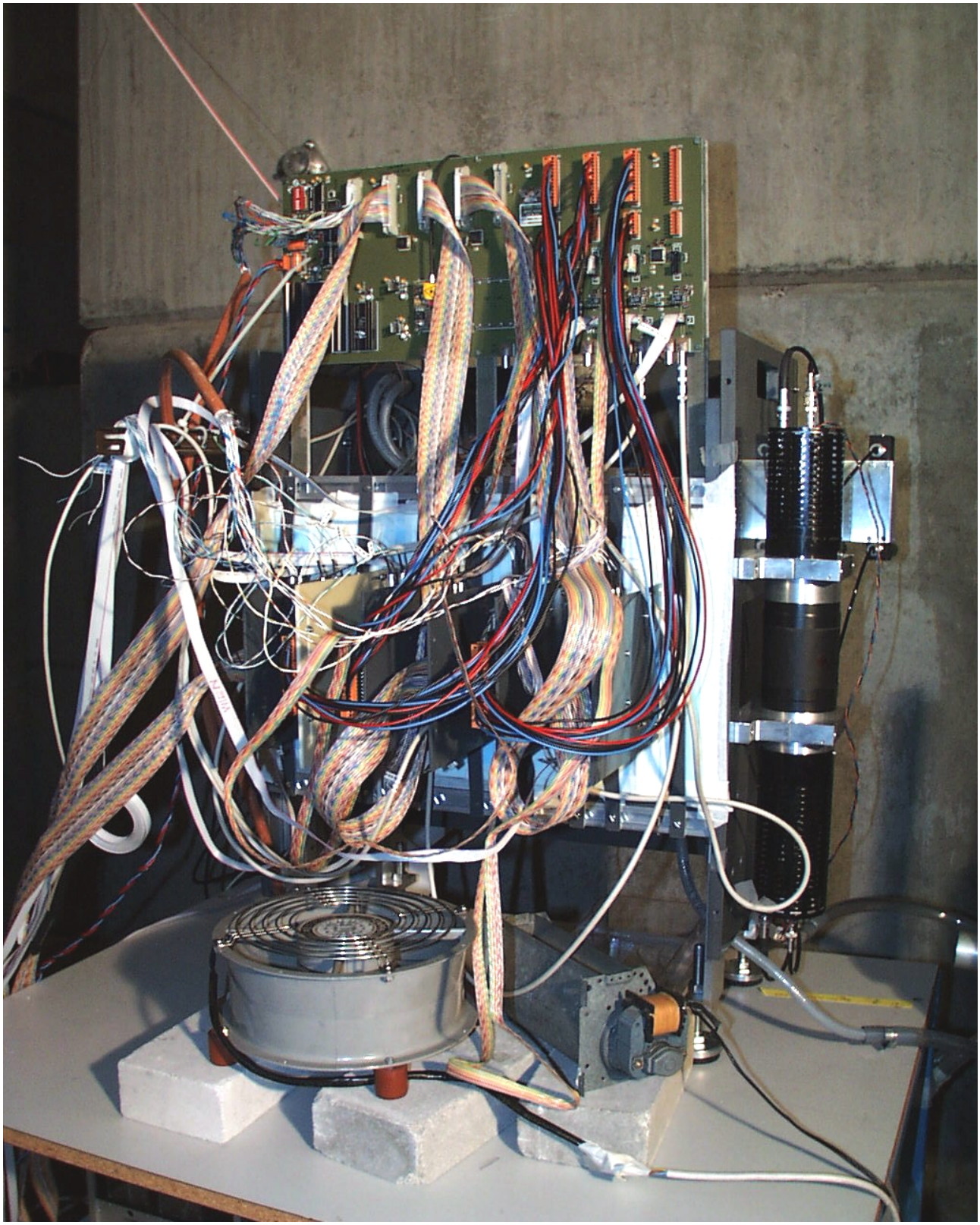
Pictures

Before installation at Paul Scherrer Institute (PSI) near Zurich

After installation in control room

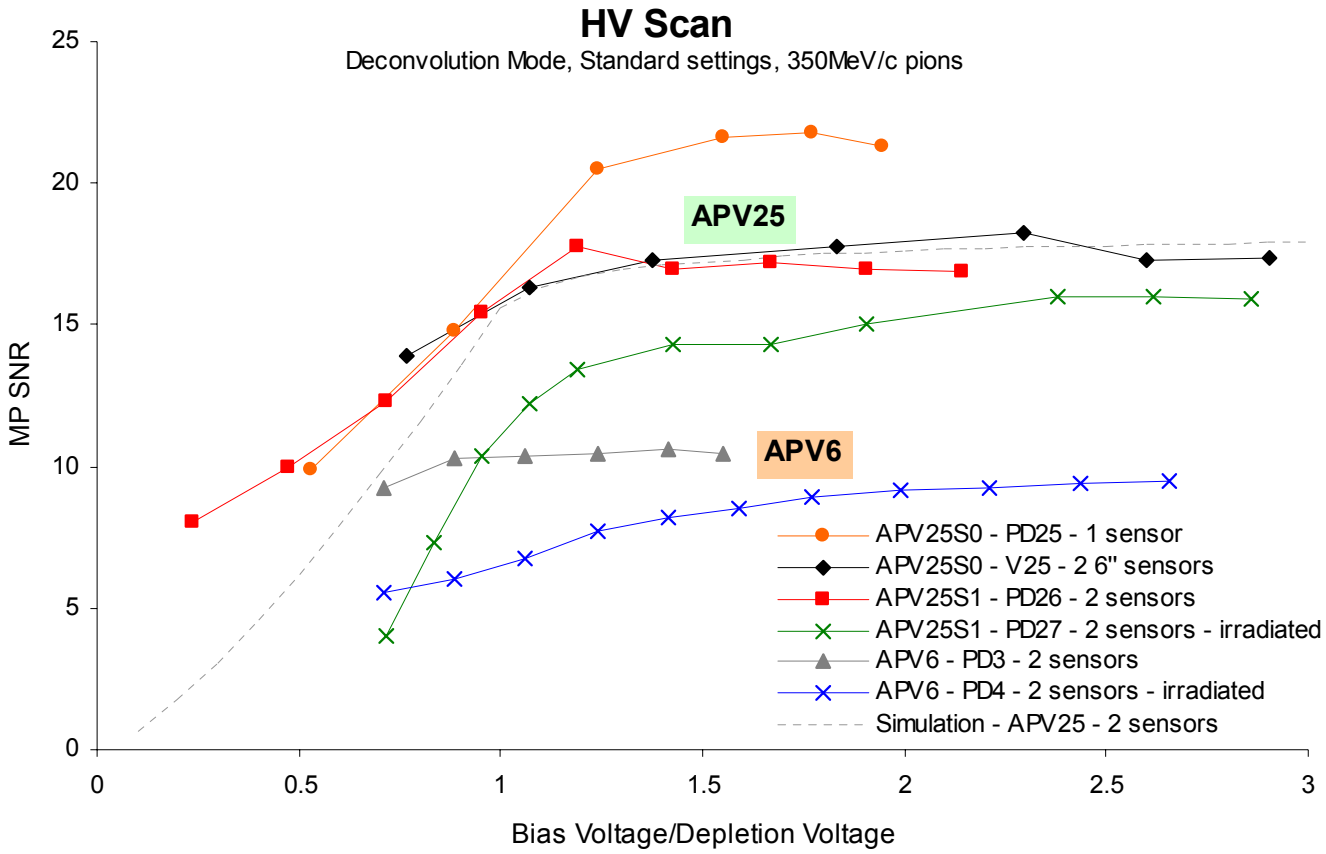


Fully equipped cooling box in beam area



Bias Voltage Scan

Selected data from beam tests



APV25

- SNR≈17 for non-irradiated full-size module at CMS operating conditions
- SNR>10 is required for ≈100% efficiency
  ⇒ sufficient margin for irradiation degradation
- APV25 outperforms previous APV6 version

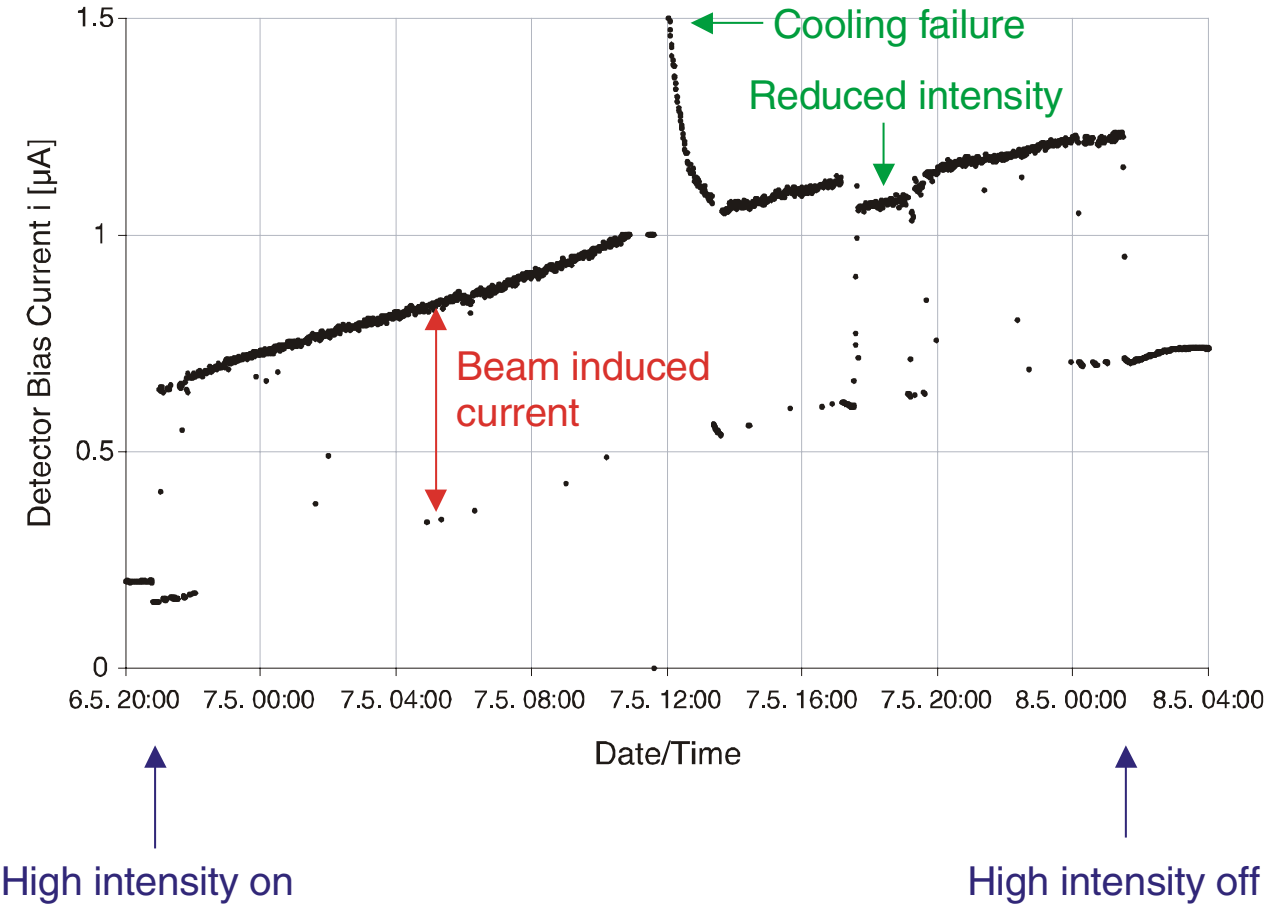
High Intensity Beam

Silicon detector

- 24 hours of LHC beam rate (1 MHz cm^{-2} – corresponds to CMS r=12 cm)
- Linear current increase, $\alpha \approx 8 \cdot 10^{-17}$ **A cm^{-1}**
- Agrees with CERN RD48 (ROSE) collaboration measurements

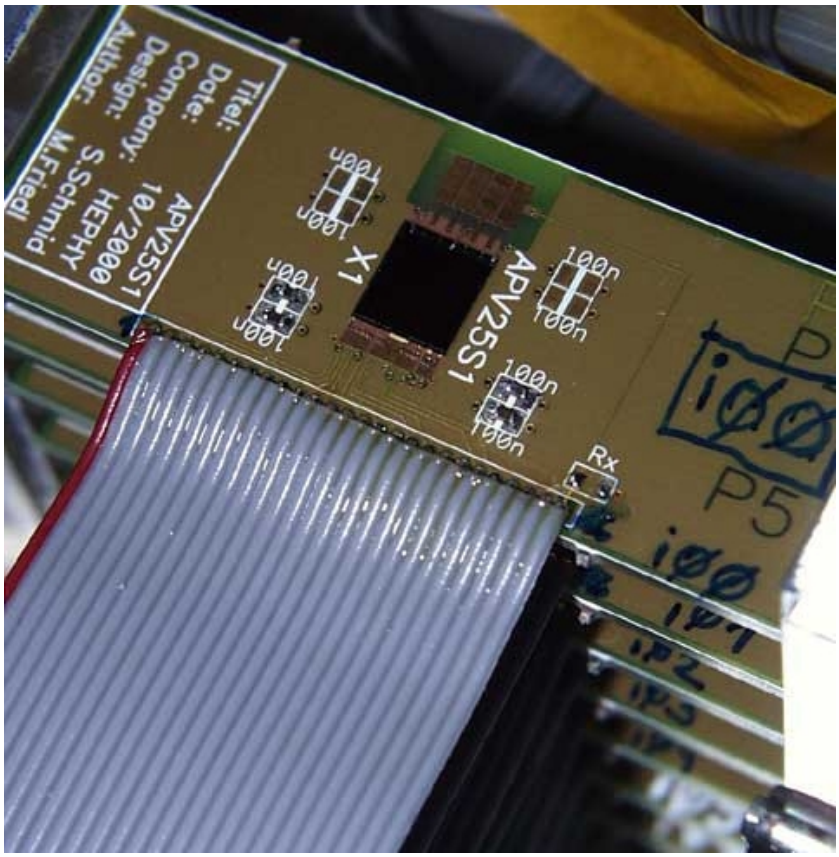
- Detector/APV25 performance unchanged

Vienna APV25 detector currents during high beam intensity



Electronics Irradiation

Why?	CMS front-end electronics must withstand hostile radiation environment
Where?	High intensity pion beam at Paul Scherrer Institute (PSI) near Zurich
What?	8 APV25 CMS front-end readout chips produced in 0.25µm CMOS

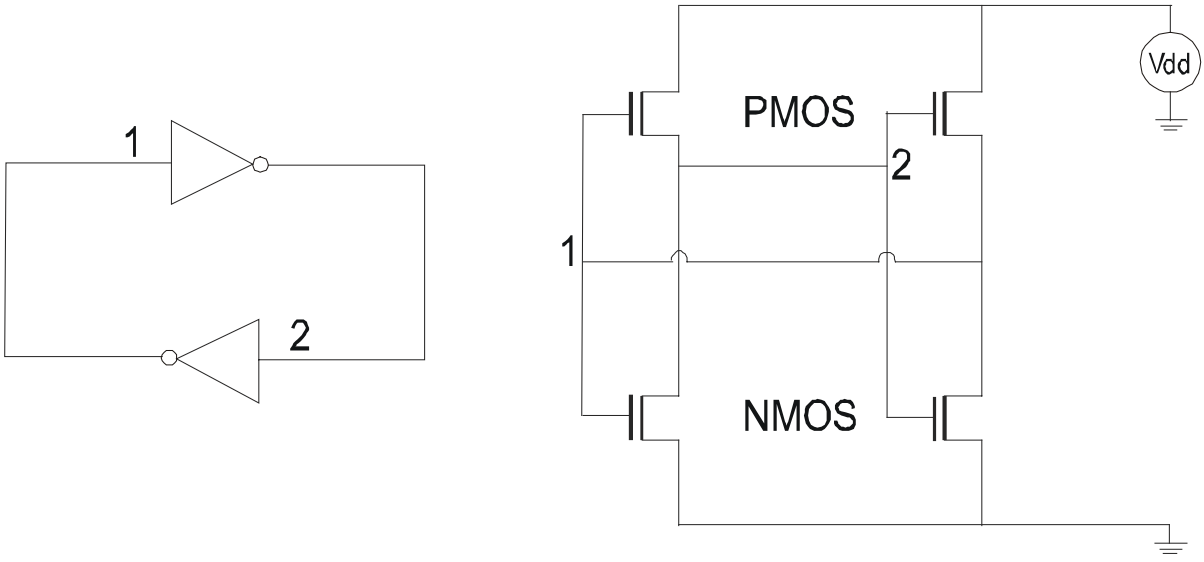


Radiation Effects

Effect	Scope	Damaging	Observed w/APV25
Single Event Upset (SEU)	digital analog	no no	yes yes
Single Event Latchup (SEL)	digital	yes	no

SEU Local charge deposition by highly ionizing particle (e.g. recoil atom)

SEU in digital logic Memory cell (flip-flop) changes state when enough charge is deposited on sensitive nodes (1 or 2)



State machine is disturbed until reset

Digital SEU Results

Cross section

More than 3000 SEUs on all 8 APVs

$$\sigma = \frac{N}{\Phi} \quad [cm^2]$$

Number of upsets divided by fluence

Measured: $\sigma = 2.25 \cdot 10^{-12}$ cm^2
(slightly depending on temperature)

Agrees with prediction from similar test with heavy ions

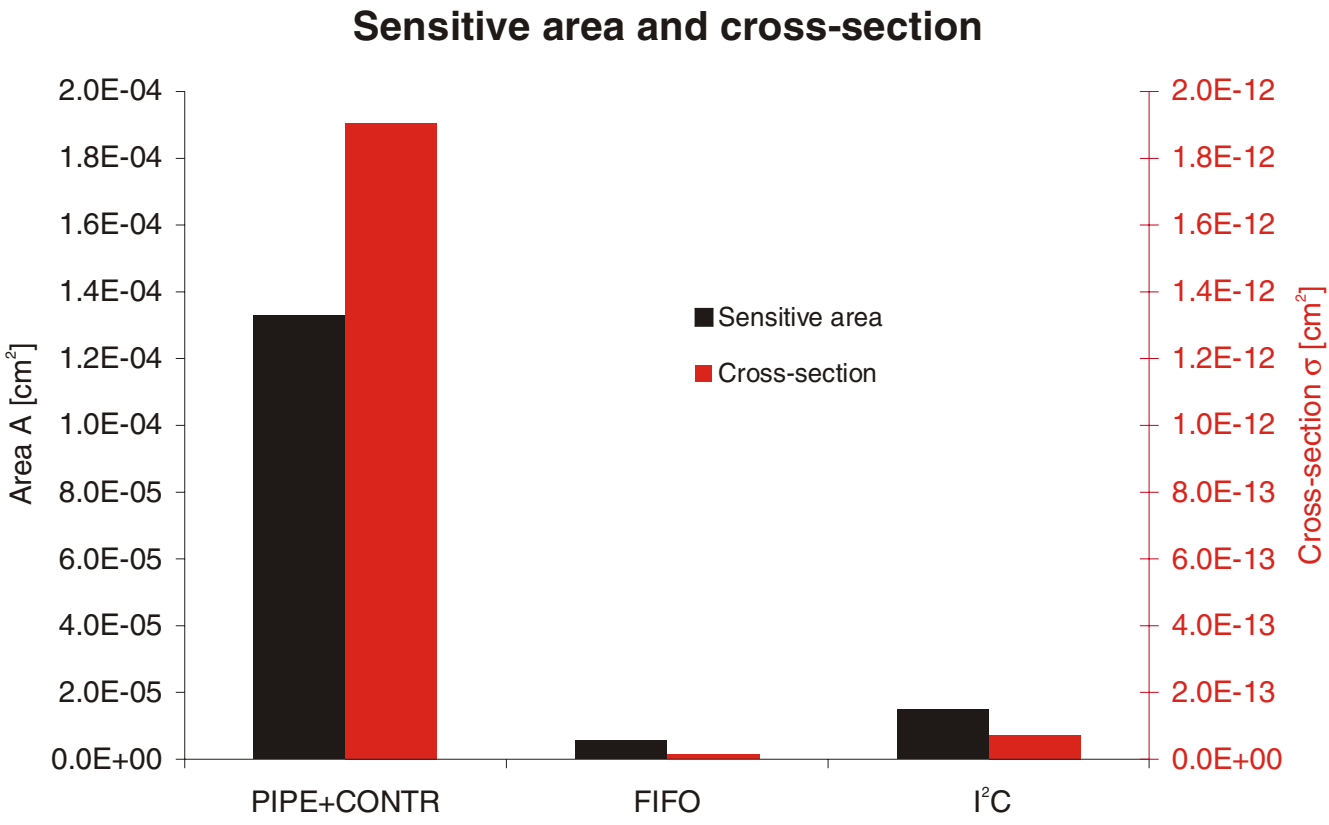
Extrapolation to CMS:

Section	Average Flux [cm^{-2} s^{-1}]	Number of APVs	Mean SEU time [s]	SEUs/time [h^{-1}]
Inner Barrel	1.40E+06	14400	22.1	162.7
Outer Barrel	4.85E+05	29232	31.4	114.7

Periodic reset required to reactivate chips whick are stuck after SEU

Cross-Section and Sensitive Area

Comparison between chip areas and SEU cross-sections of different logic blocks



Principal agreement

Exact cross-section depends on electrical and geometrical circuit layout

Summary

CMS @ LHC	Future high energy detector experiment / accelerator at CERN
Electronics	Full APV readout system developed at HEPHY
	Important contributions to the CMS Silicon Tracker R&D:
Silicon Detector	Prototype modules were assembled and successfully tested in particle beams
	Excellent SNR obtained
Radiation effects	Detectors: Linear current increase observed
	Electronics: Single Event Upset cross section measured
	Many more results within my thesis
Web	http://cern.ch/friedl → Dissertation