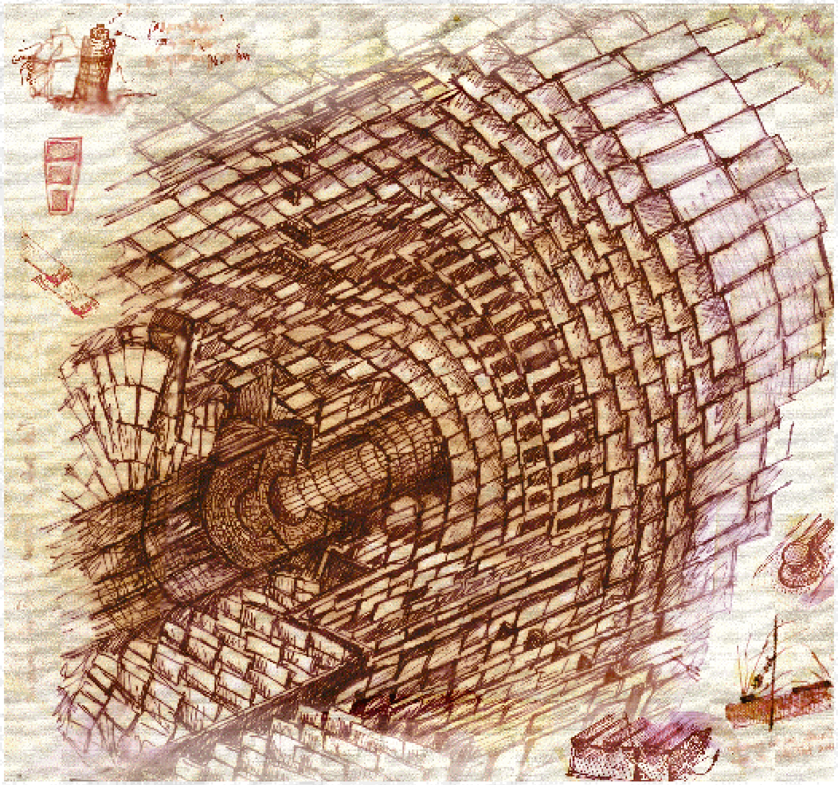
Progress on CMS Silicon Tracker



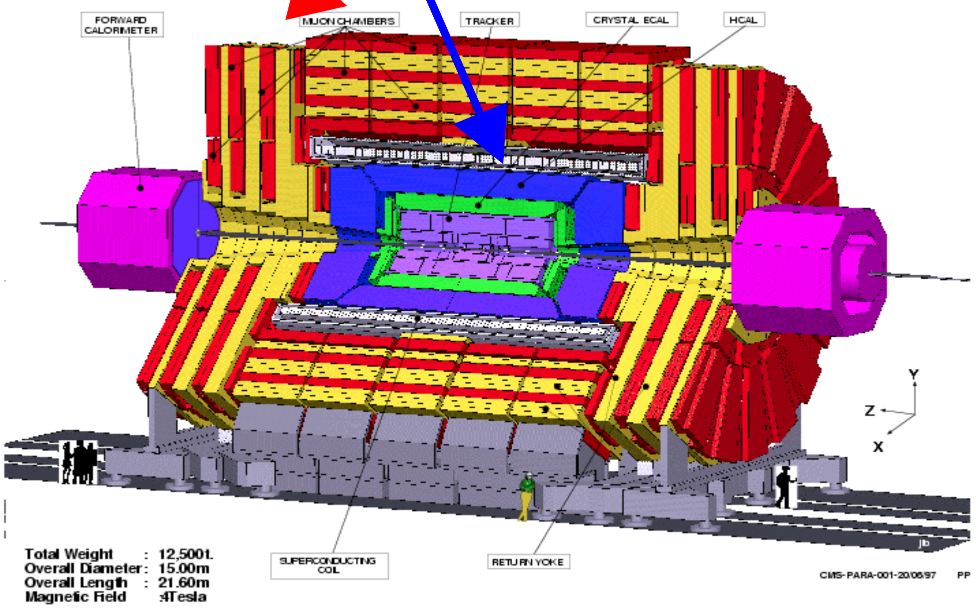
I.Stavitski

INFN Padova

CMS @ LHC

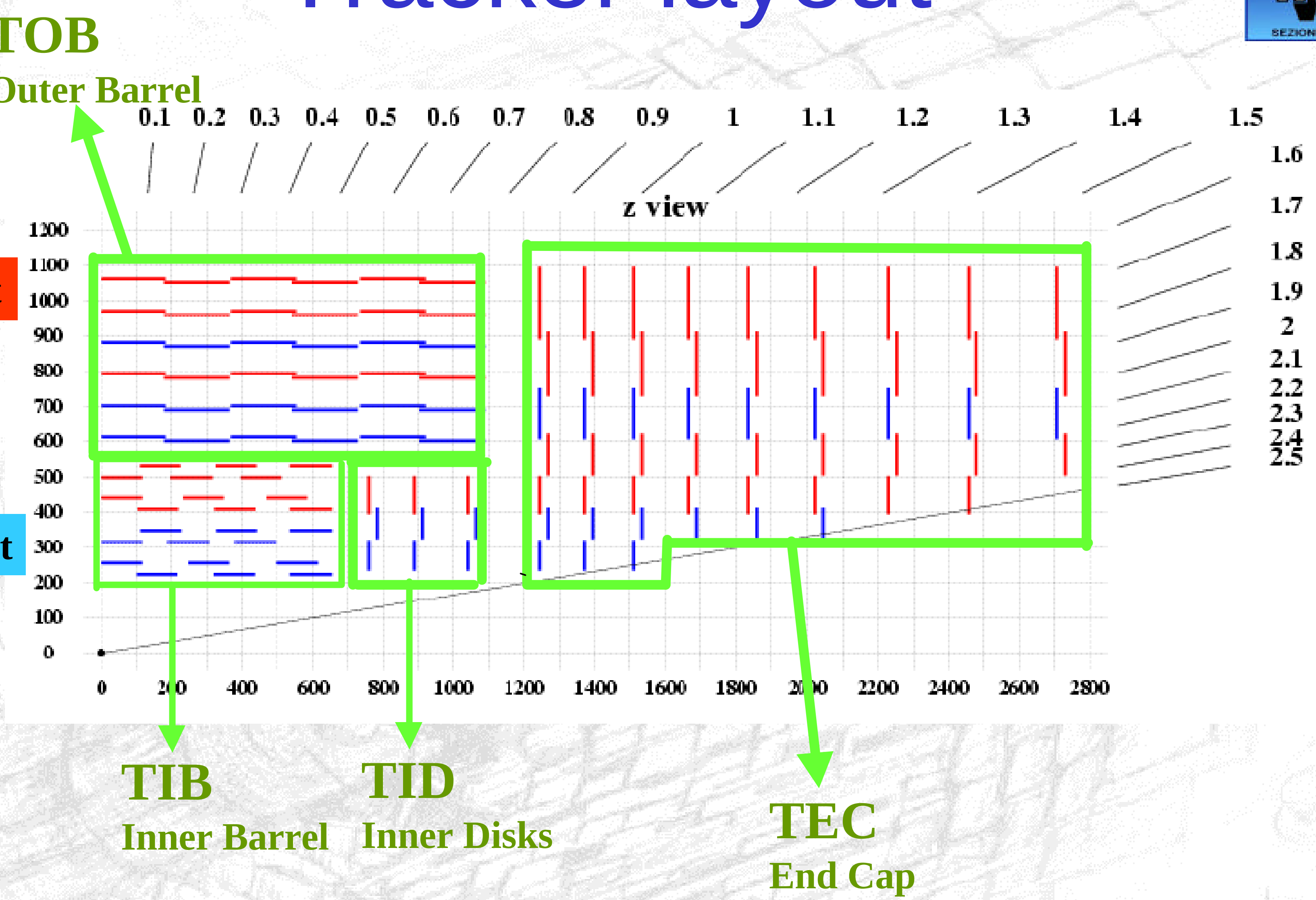
Main design features:

1. a very good redundant muon system
2. best possible EM calorimeter
3. a high quality, high granularity central tracking system



Main purpose:
to search of the Higgs boson in the mass range 90-1000 Gev, explore the b,t sector of SM and search of SuSy manifestation.

Tracker layout



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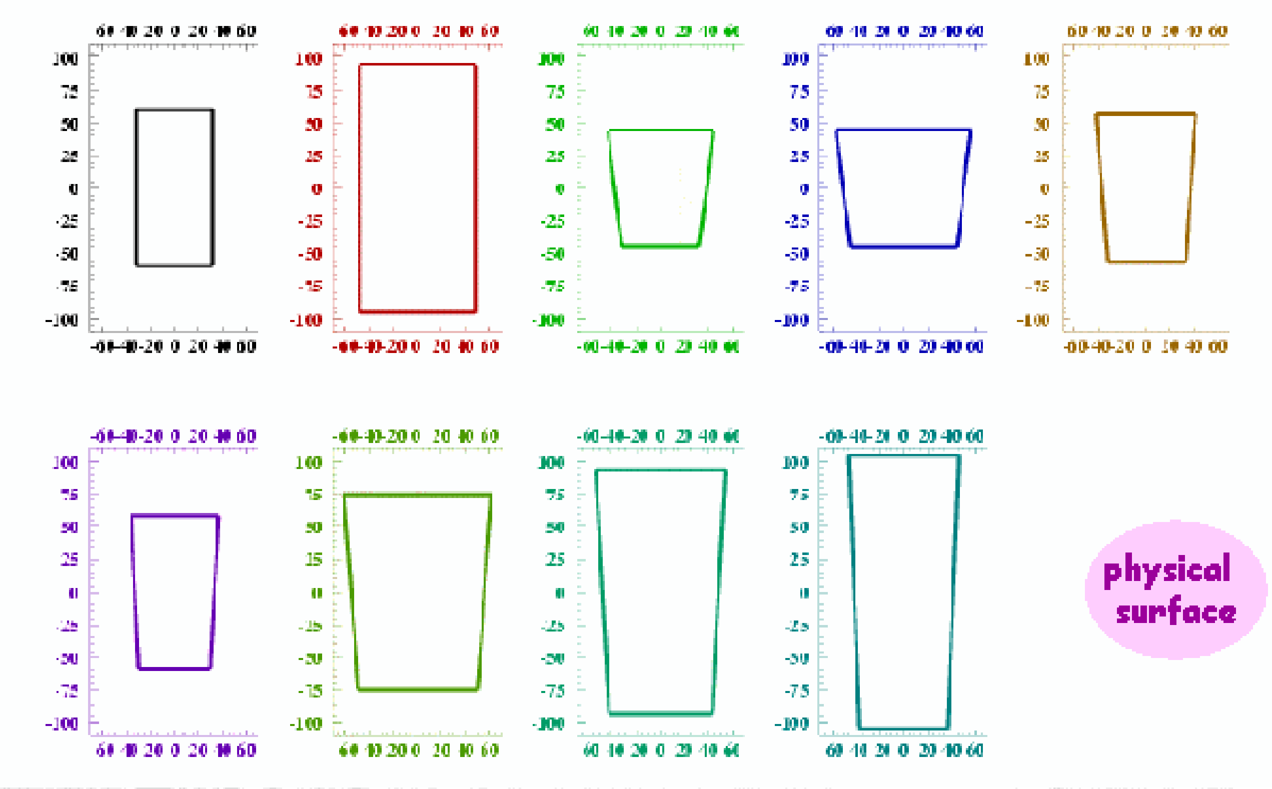
Sensor’s pool

Sensors produced on 6” wafers

Pitch IB 80 - 120 µm 6-4 chips/module
OB 122-183 µm 6-4 chips /module
ID 81/112-123/158 µm



Tracker summary

6,136 Thin wafers 300 µm

19,632 Thick wafers 500 µm

6,136 Thin detectors (1 sensor)
9,816 Thick detectors (2 sensors)

3112 + 1512 Thin modules (ss +ds)
4776 + 2520 Thick modules (ss +ds)

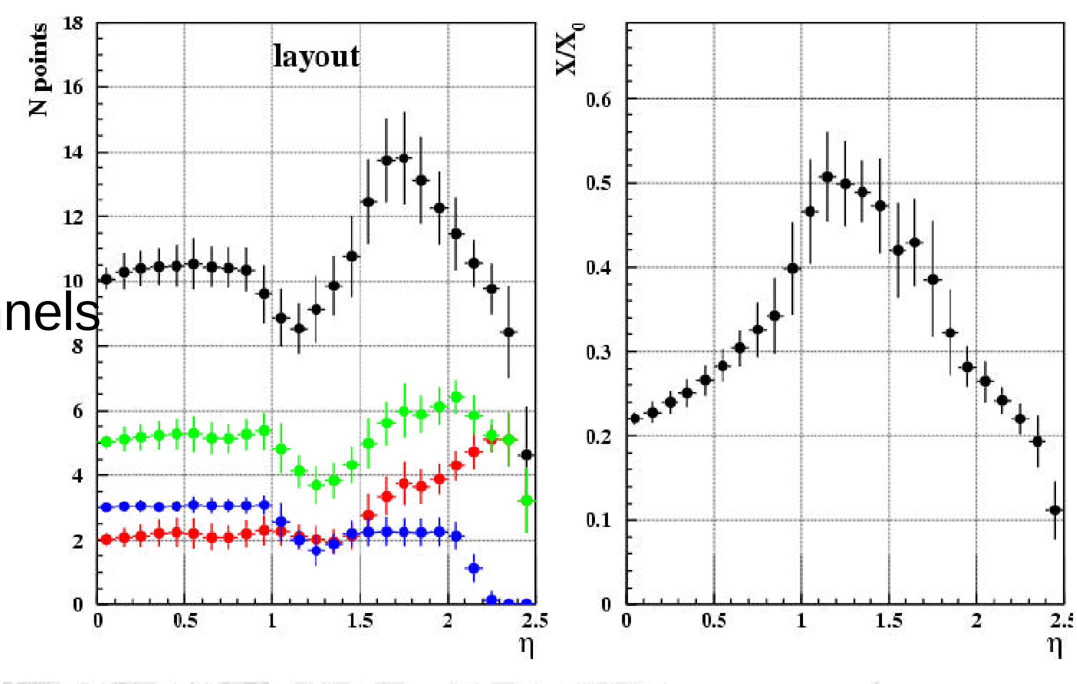
10,016,768 strips and electronics channels

78,256 APV chips

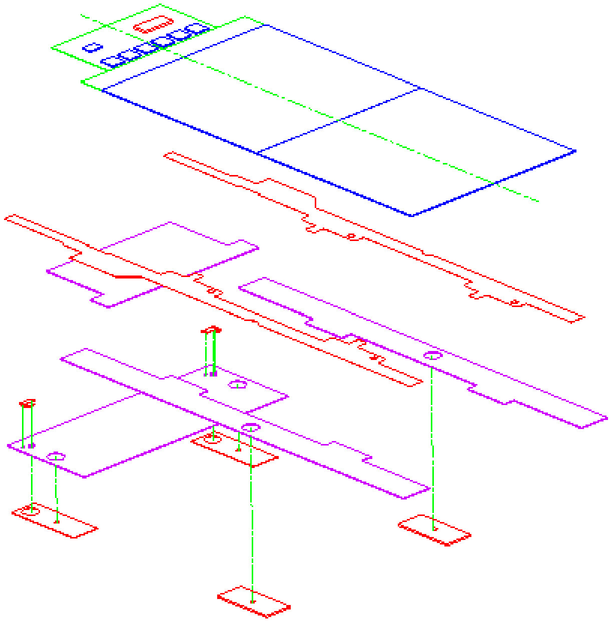
26,000,000 Bonds

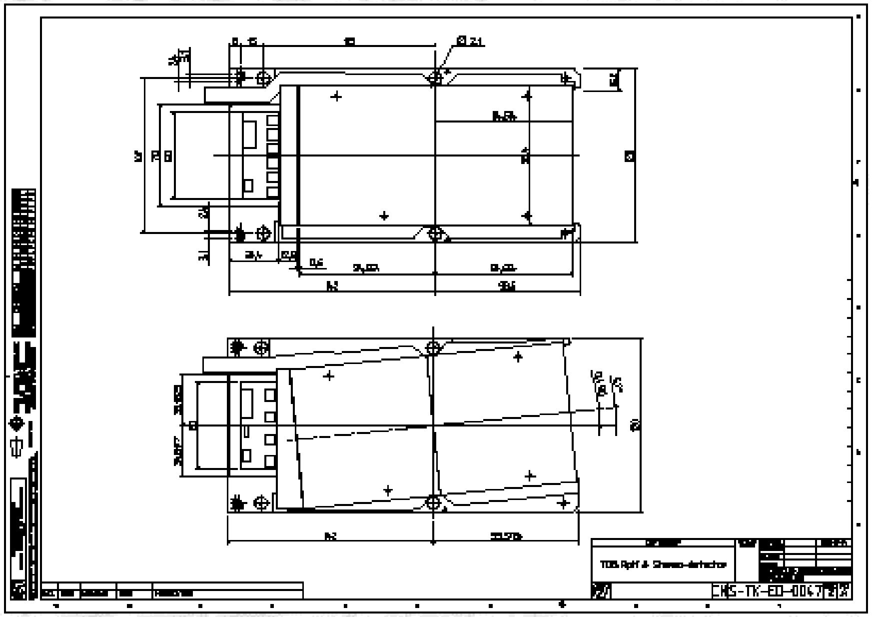
470 m^2 of silicon wafers
223 m^2 of silicon sensors (175 m^2 + 48 m^2)

N of points in the SST:
Total, double, double inner, double outer.



Modules construction



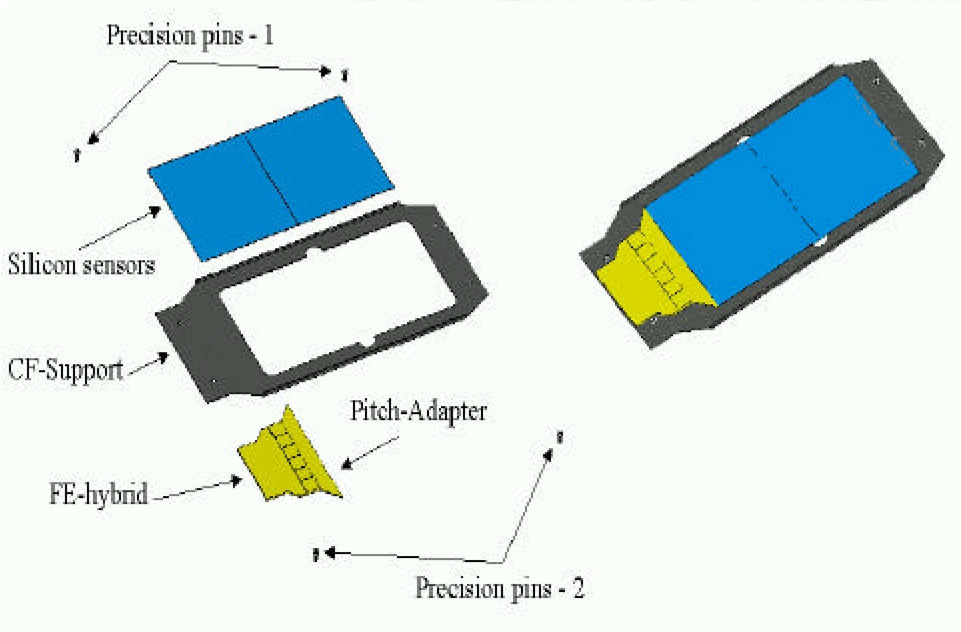


The module consists essentially of three elements:
- **the silicon sensors**
- **the mechanical support structure and heat transport elements**
- **the read-out hybrid**

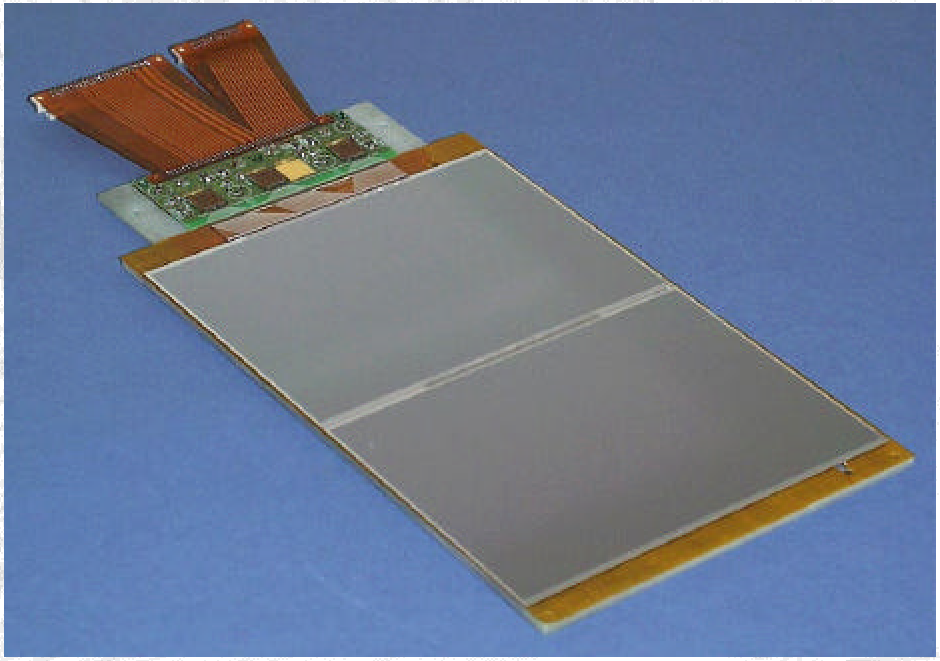
Double sided modules are achieved joining together two mechanically independent detectors, the r-Ø and the stereo detectors

Layout of the modules

Inner single sided.

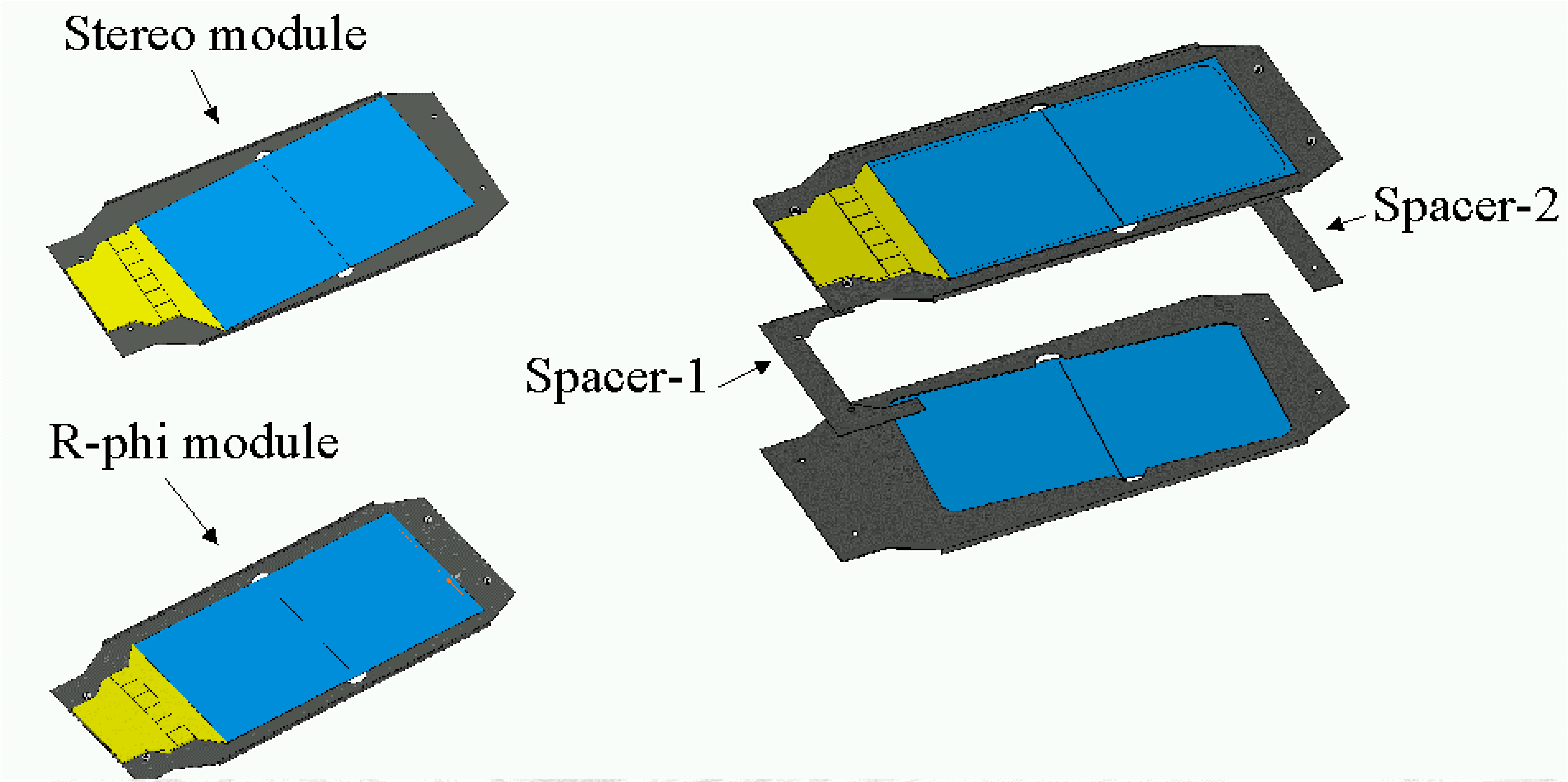


...and prototype produced for tests.



Layout of the modules

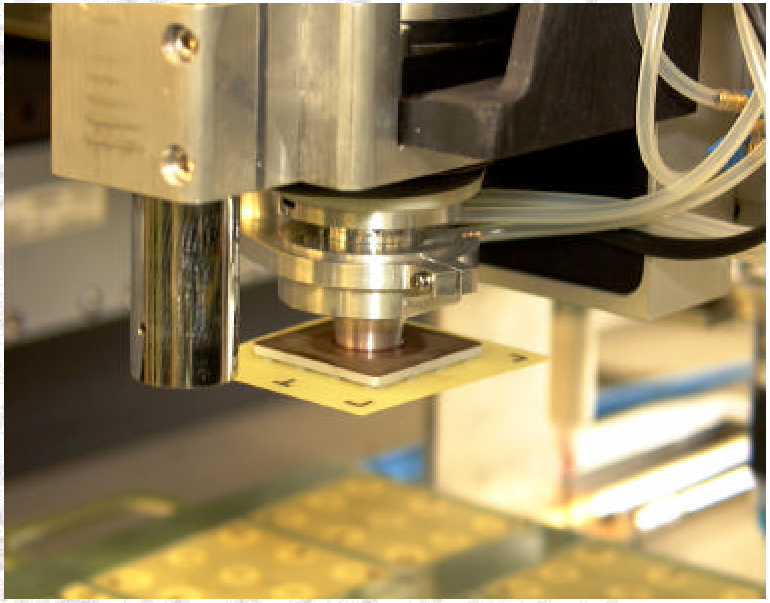
Inner double sided - back2back technology.

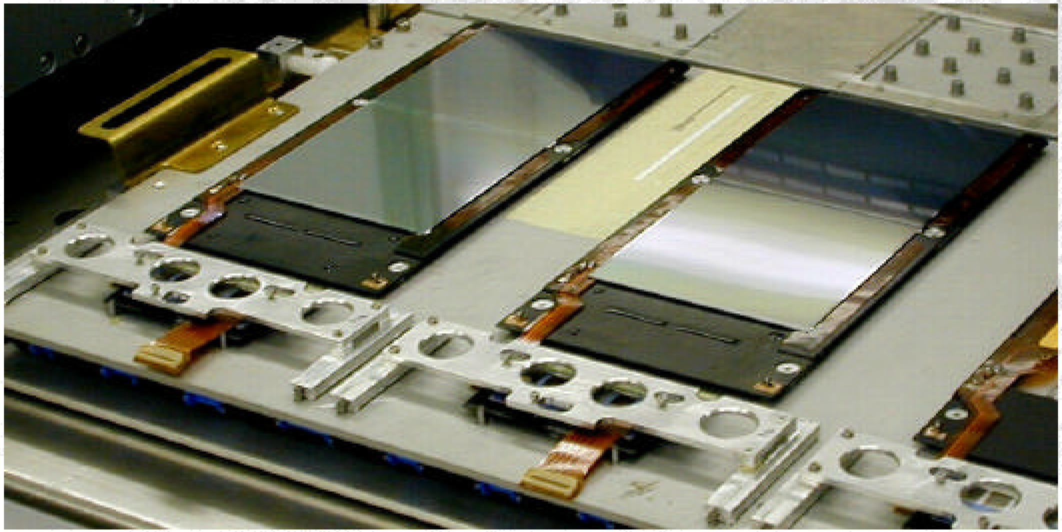


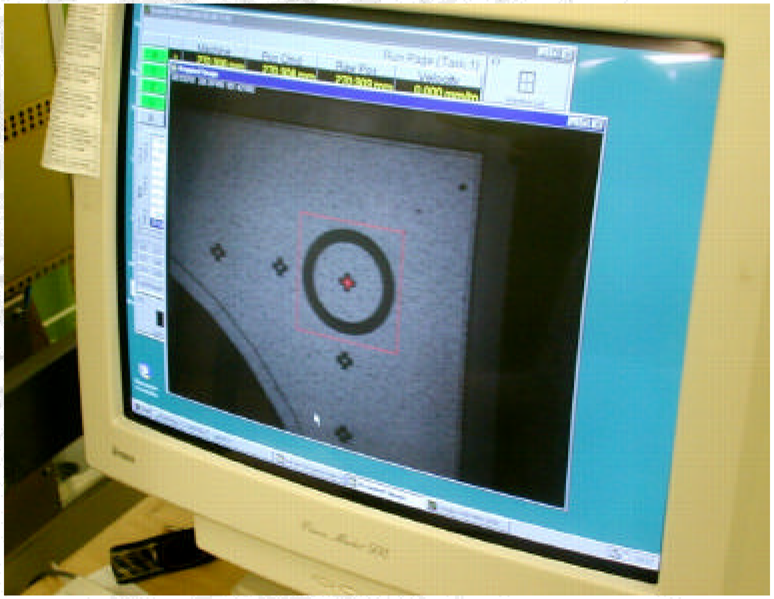
Automatic approach

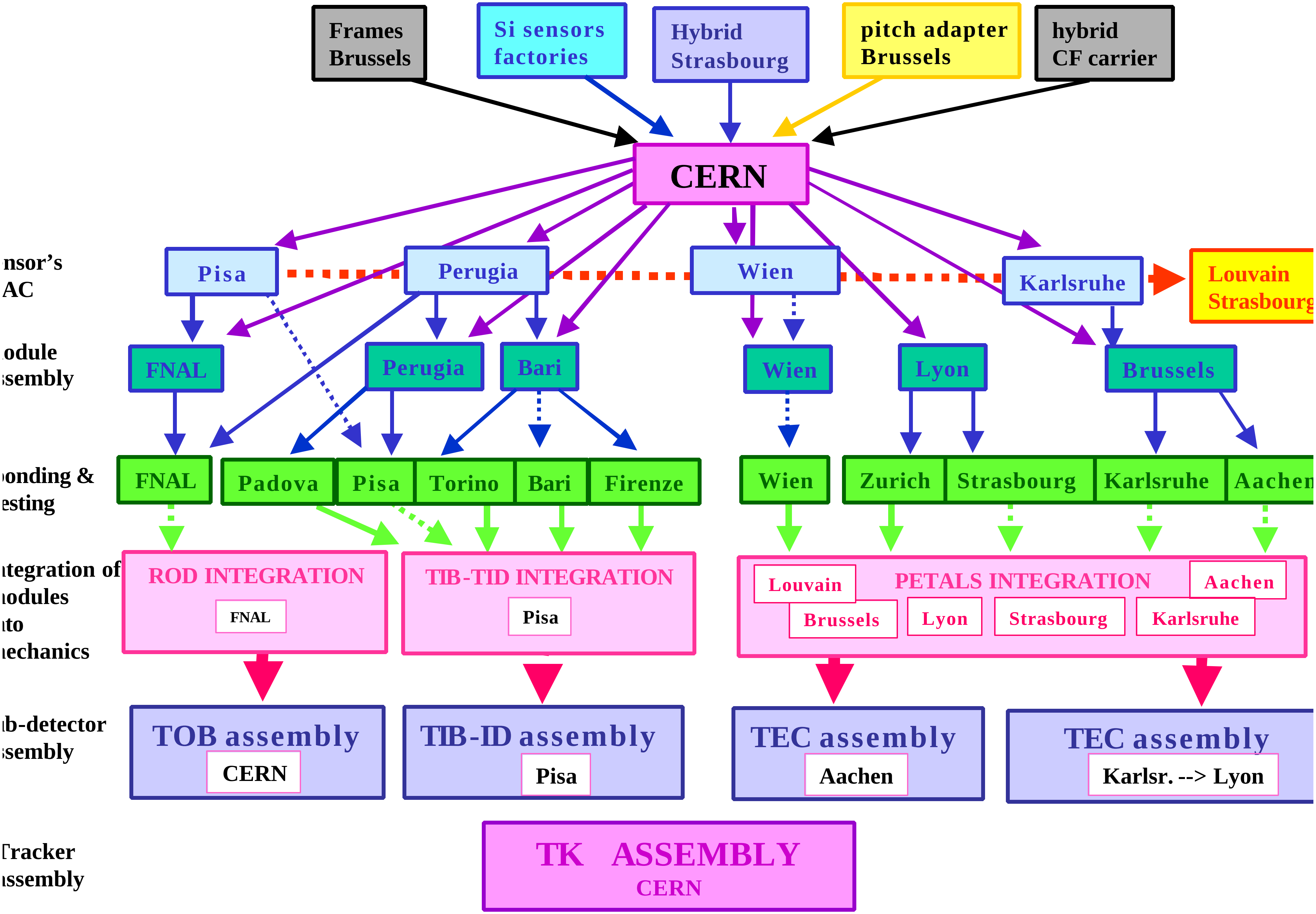
Special robot - GANTRY - is developed
for assembling CMS Si tracker.

Positioning accuracy 1.6 µm
productivity 10 min/module









Frames Brussels

Si sensors factories

Hybrid Strasbourg

pitch adapter Brussels

hybrid CF carrier

CERN

nsor’s
AC

Pisa

Perugia

Wien

Karlsruhe

Louvain
Strasbourg

odule
ssembly

FNAL

Perugia

Bari

Wien

Lyon

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Padova

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Torino

Bari

Firenze

Wien

Zurich

Strasbourg

Karlsruhe

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ROD INTEGRATION
FNAL

TIB-TID INTEGRATION
Pisa

PETALS INTEGRATION
Louvain
Aachen
Brussels
Lyon
Strasbourg
Karlsruhe

b-detector
sembly

TOB assembly
CERN

TIB-ID assembly
Pisa

TEC assembly
Aachen

TEC assembly
Karlsr. --> Lyon

Tracker
ssembly

TK ASSEMBLY
CERN

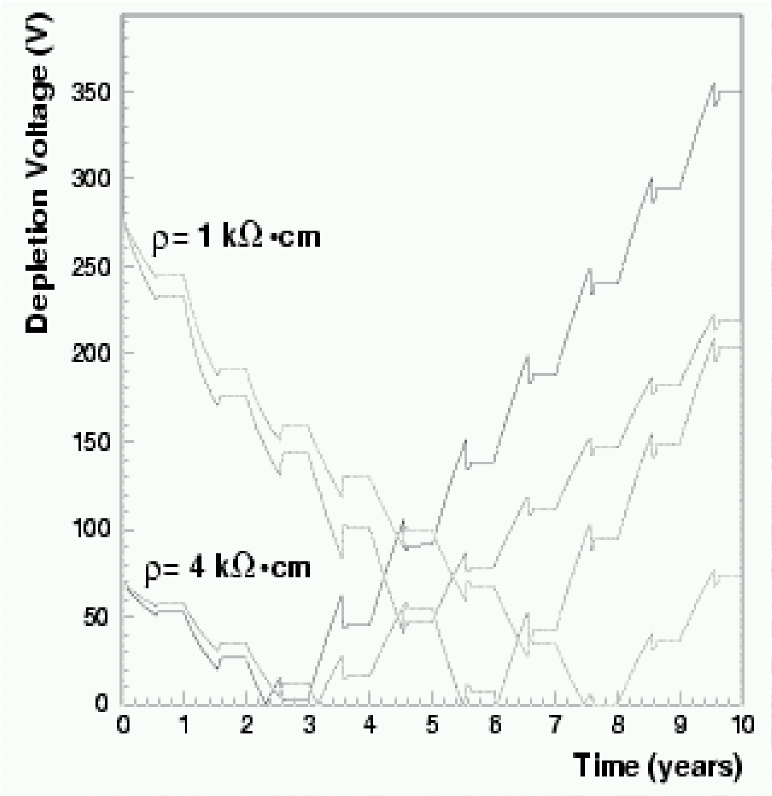
Padova activity in CMS

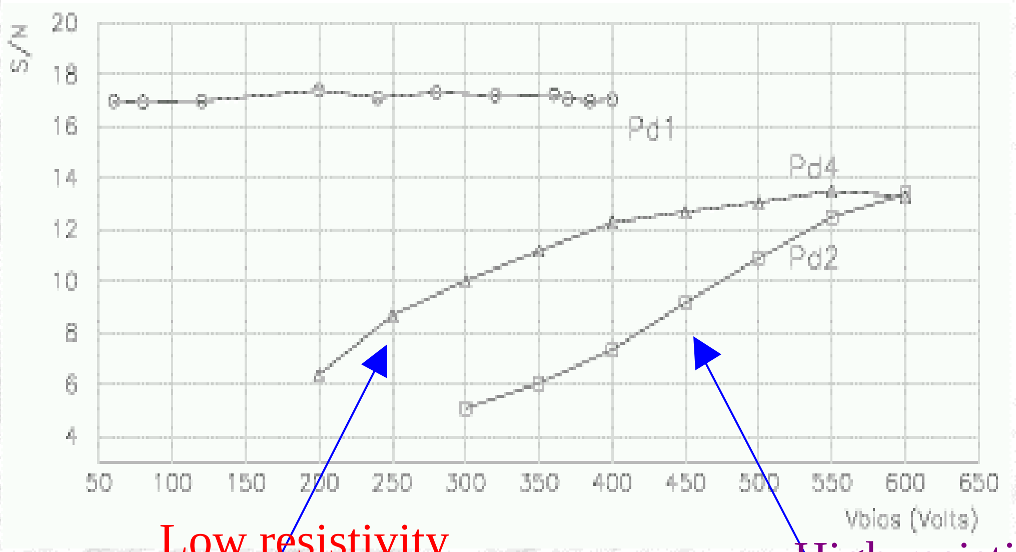
1995 tests of PreShape
1996 first test beam with microstrip detectors, irradiated behind type inversion
and front-end chip PREMUX - the resolution and efficiensy are good.
1997 test beam with full size prototypes of CMS Tracker modules, irradiated
at 2×10^{14} n/cm^2, cooled below -10 ^{o}C -
1998 experience with testing APV6 at laboratory and beam test with
2 chips modules - no signal, but good feedback to the electronics, DAQ and
software improvement.
1999 first results with APV6 at the beam - s/n = 17 (12) ni and 12(6) irr
outstanding performance of low resistive <100> Si
tests of SEU on APV6
beginning to test APV25
radiation tests of APV25 - chip is radhard
2000 first test of module with APV25 at the particle beam (π, 350 MeV/c @ PS
chip shows very good performance - s/n = 22 (16) ni and 18(12) irr
SEU measurements of APV25s1
beam test of oxygenated Si modules with APV25S1
2001 test of CCE of oxygenated Si with APV25

Radiation hardness

Using the lower resistivity silicon for innermost layers shows an advantage after irradiation.

Test beam with detectors irradiated at 2.1×10^{14} n/cm^2

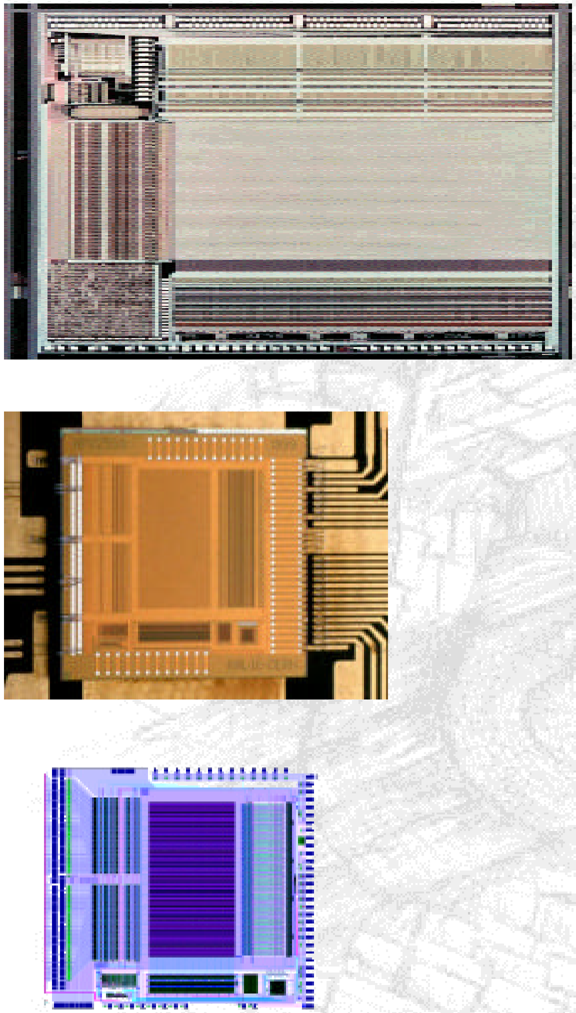




Low resistivity
1.4 kOhm cm

High resistivity
6 kOhm cm

Test of APV front-end chip



APV6 1.2 m Harris AVLSIRA radhard CMOS

APV25-S0 (Oct 1999)

Longer pipeline 192 *[160]*

Deeper buffers 10 (x3) *[6 (x3)]*

S/N improved 2000/0.36 PMOS @ 400µA *[3000/1.4 PMOS @ 500µA]*

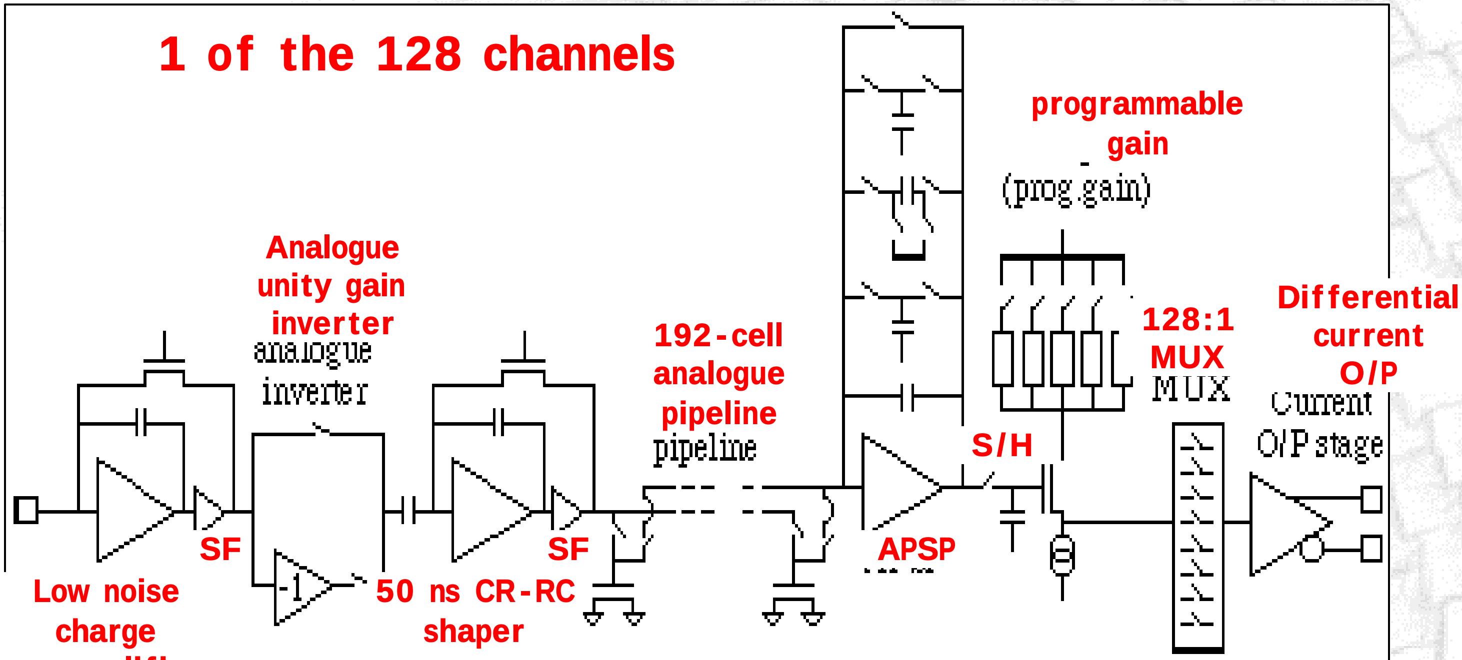
Switchable input polarity & differential output

Reduced size 57mm^2 *[77mm^2]*

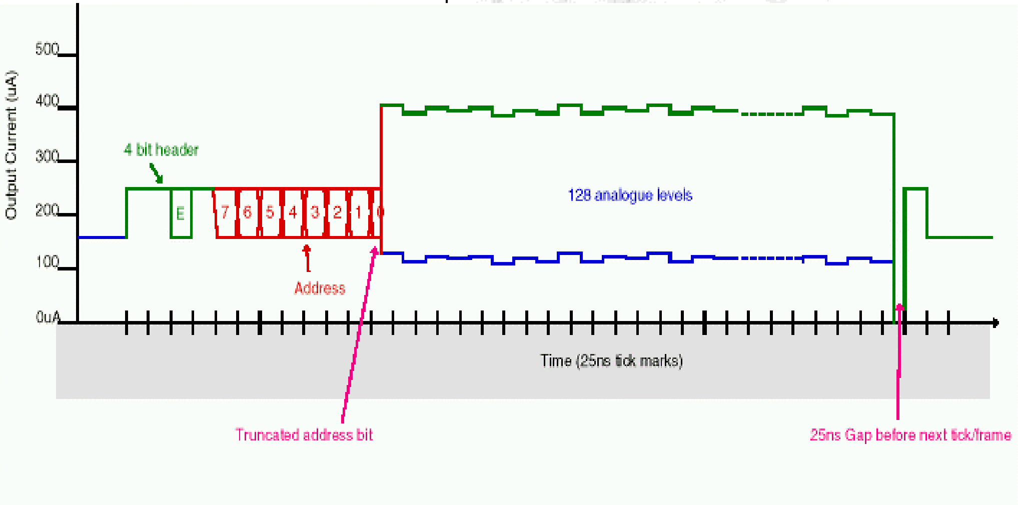
Reduced power 2.3mW/channel *[2.4 + MUX]*

APV25-S1 (Aug 2000) Final

Test of APV front end chip

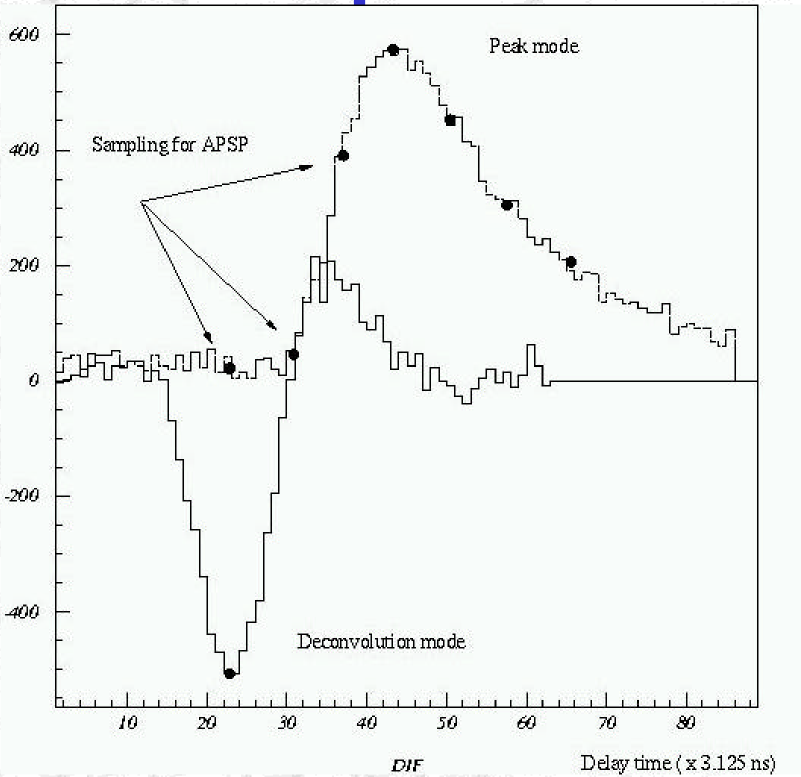


Schematic and output of the chip

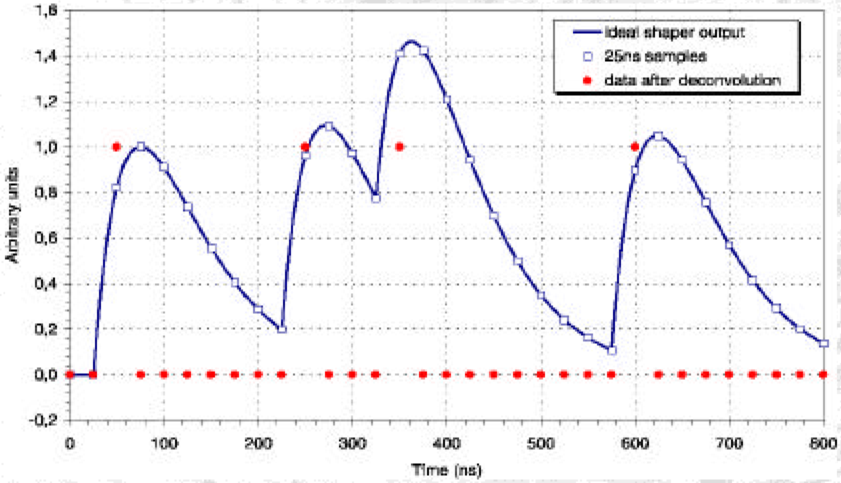


APV front-end chip

Chip is designed to work in two modes : peak and deconvolution.
In deconvolution mode APSP filter is activated and using 3 samples from the pipeline, deconvolute 50 ns output to the 25 ns.



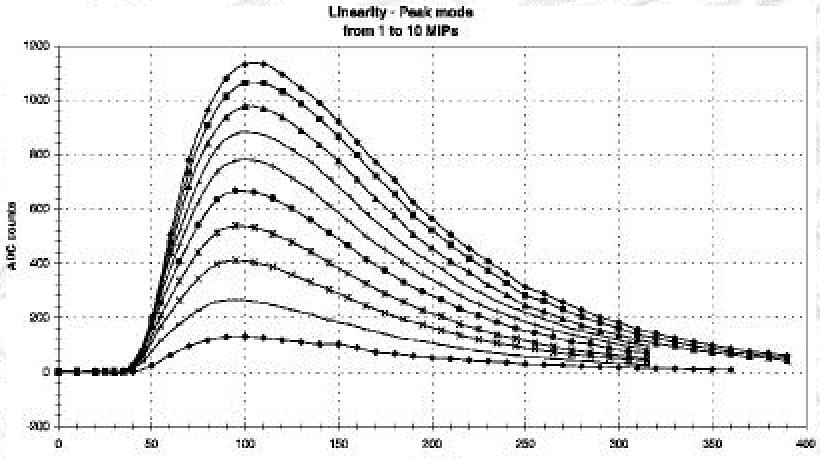
This permits avoid a pile-up of the output in case of the high rate events (high luminocity operation), but the noise is higher.

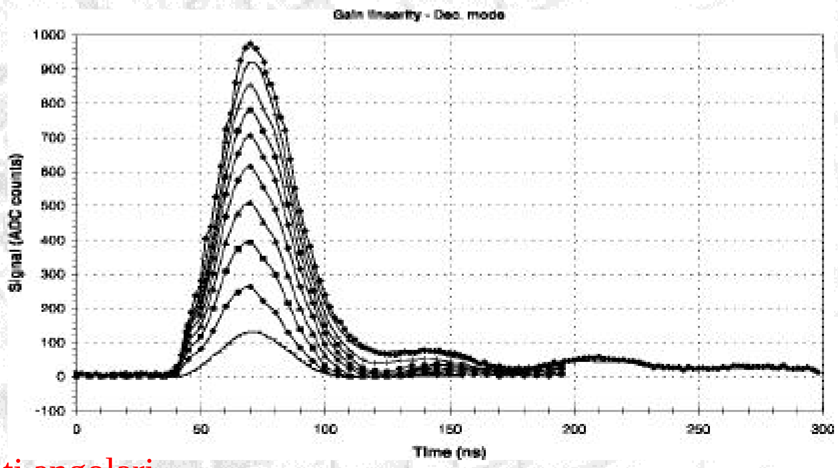


APV25 test

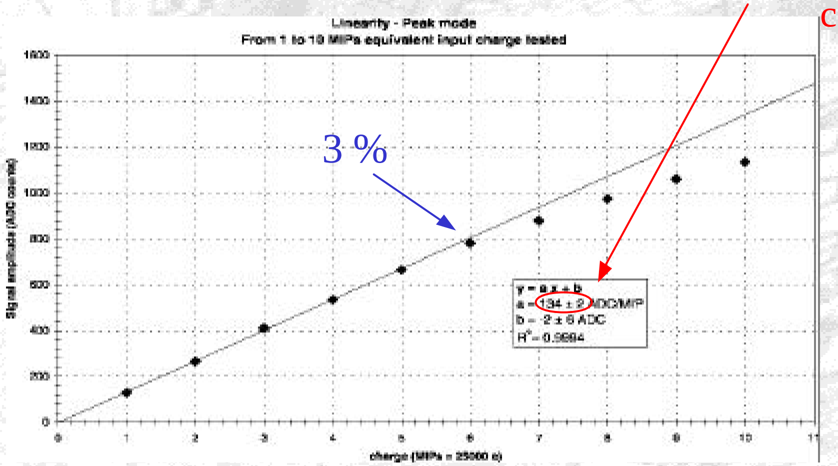
Peak mode

Deconvolution mode

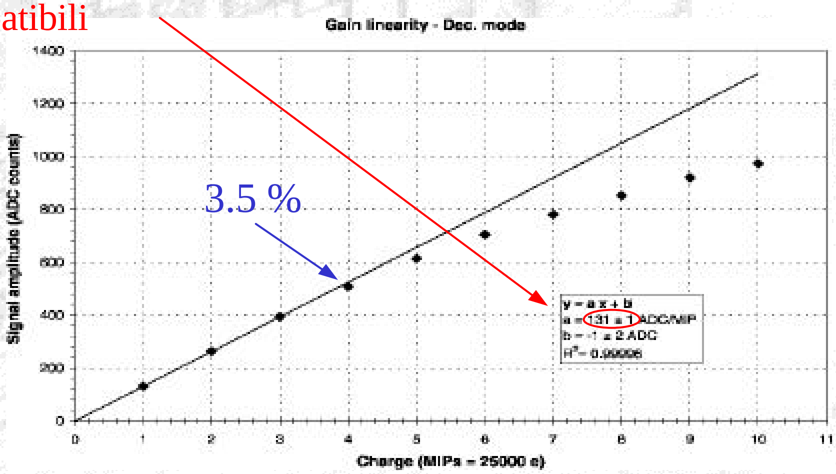




Coefficienti angolari compatibili



3 %



3.5 %

APV25 test

- shot noise of the leakage current I_L
- bias resistence R_b thermal noise
- feedback resistance R_F
- serial resistence R_s
- termal noise of the channel PMOS
- flicker of PMOS

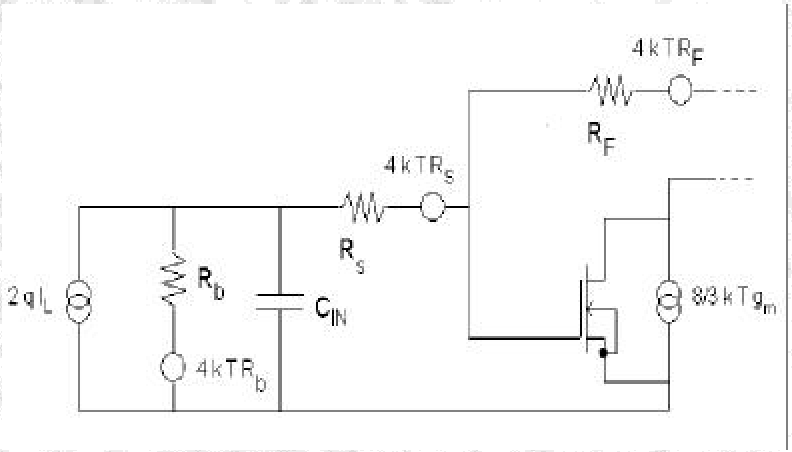
Capacitance is major issue

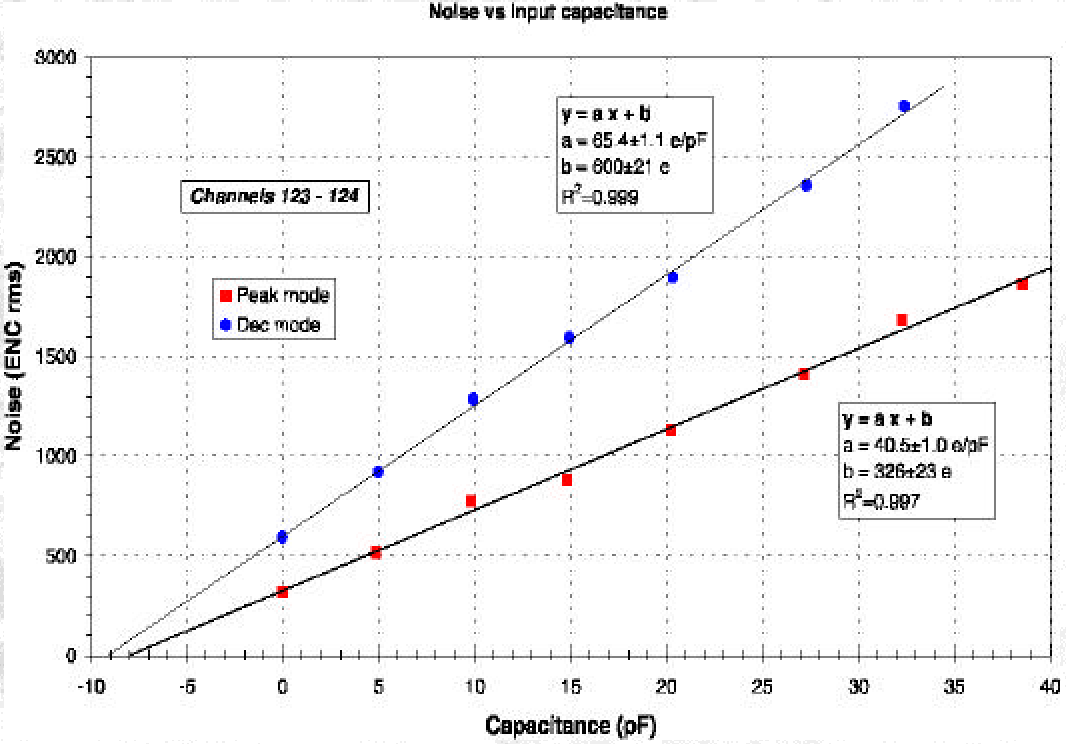
$$\mathrm{ENC} = a\,C_{IN} + b$$

$$\mathrm{ENC}_{dec.} \approx \sqrt{3}\ \mathrm{ENC}_{peak}$$

270 +38 ENC/pF

430 + 61 ENC/pF

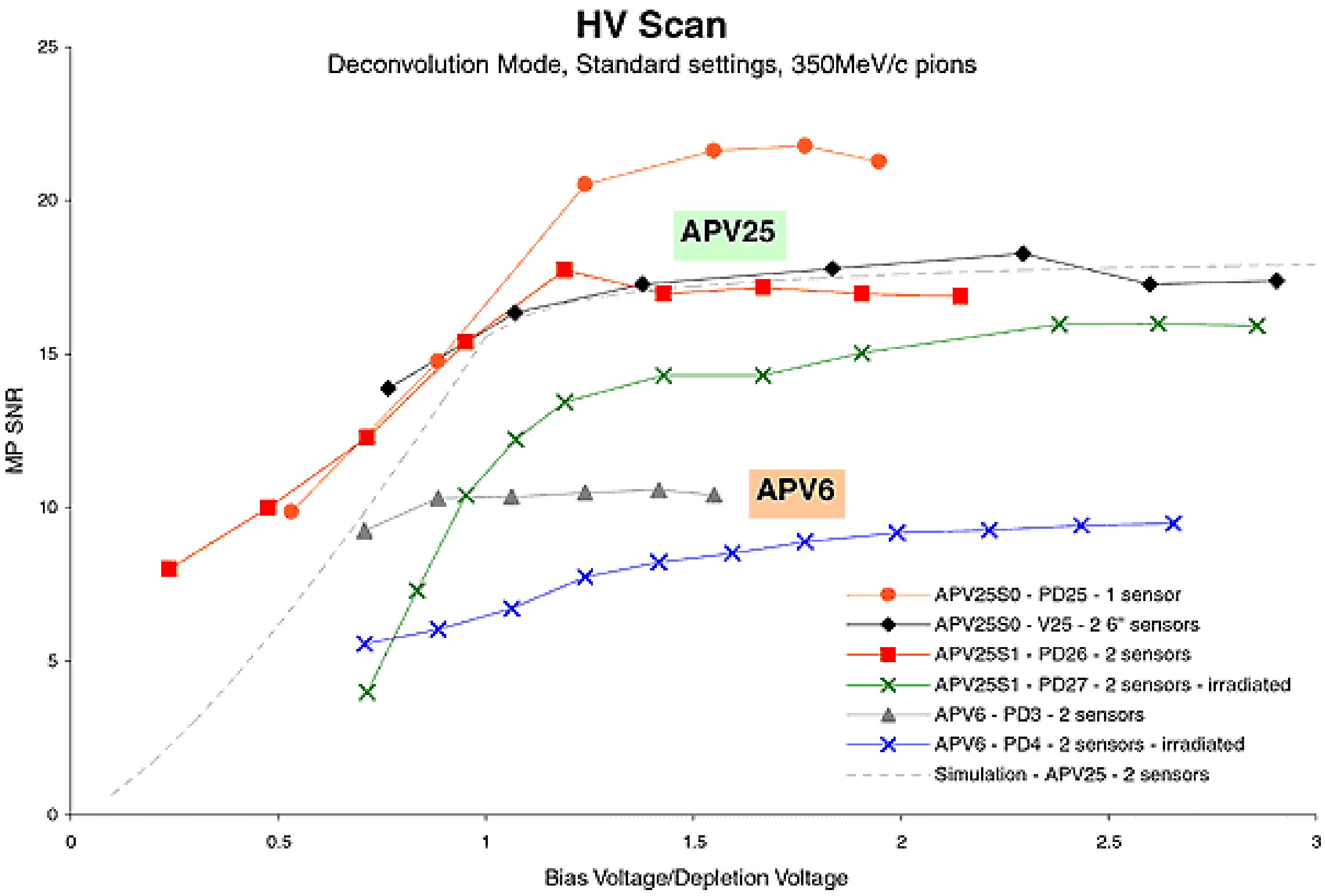




Detectors on the test beam

PD

Test beam performance of various prototypes showing an advantage of the APV25 chip



I.Stavitski *INFN Padova*

APV25 - test of radhardness

CMOS hard against bulk damage

Can be qualified with ionising sources only

Typical irradiation conditions

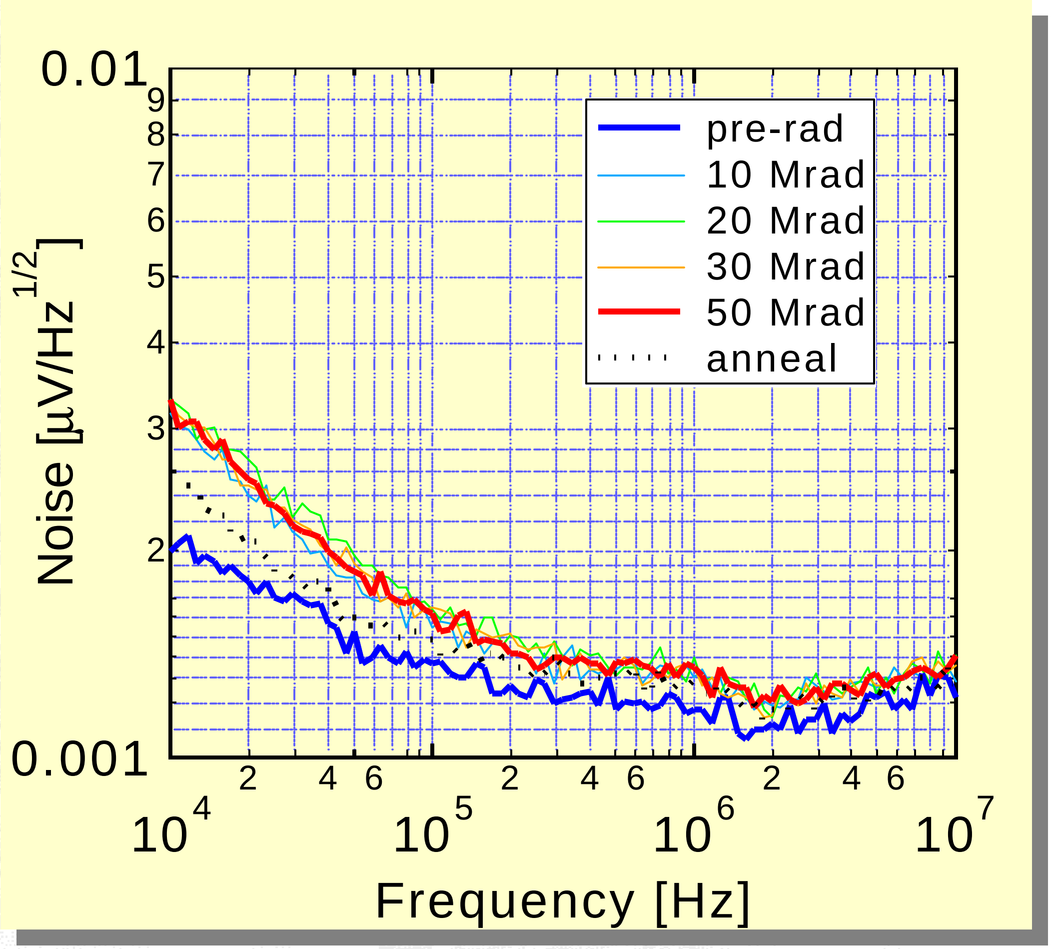
50kV X-ray source

Dose rate ~ 0.5Mrad/Hour

to 10, 20, 30 & 50Mrad

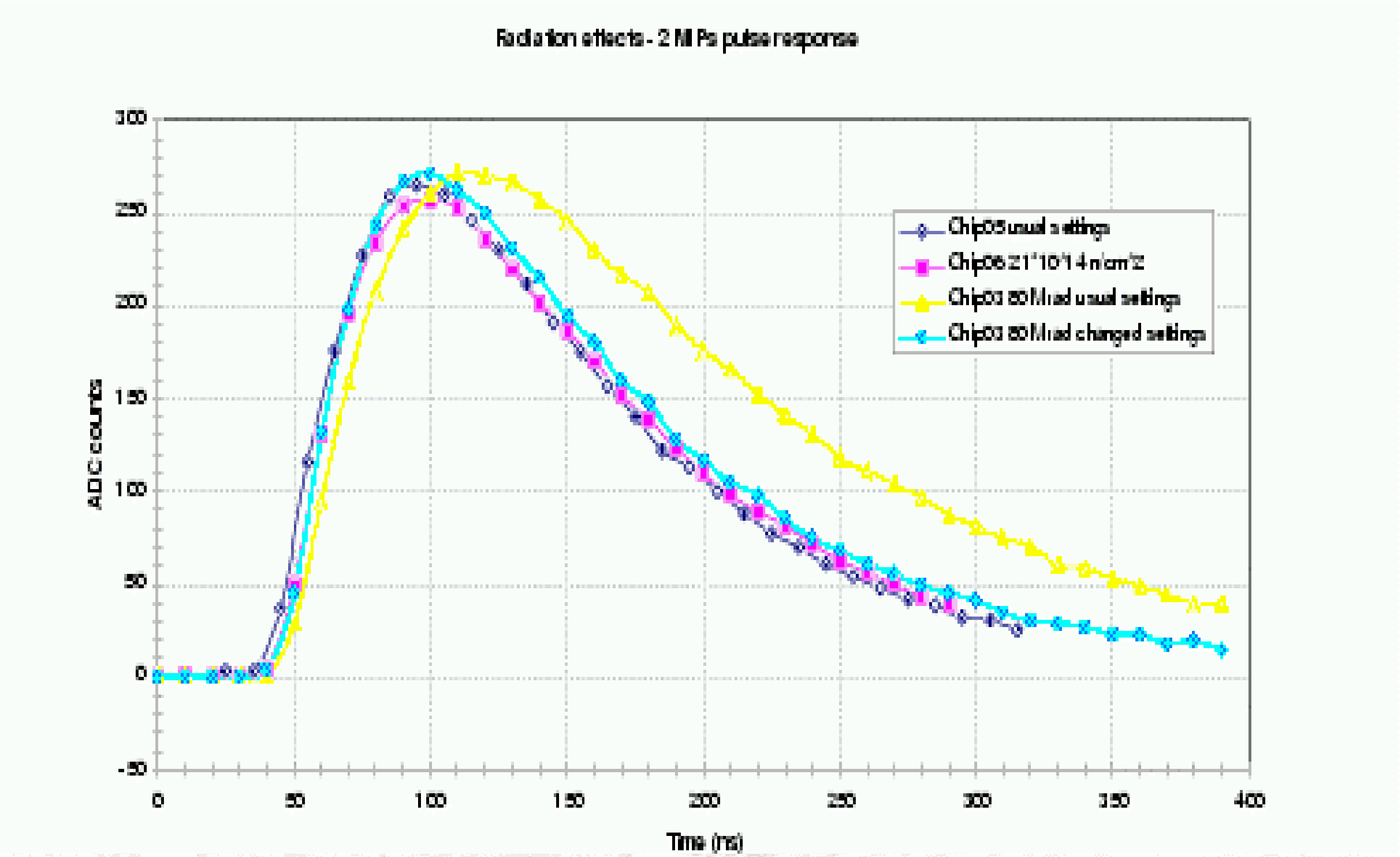
dosimetry: Si diode ~10% precision

Anneal: 1 week at 100^{o}C



APV25 - test of radhardness

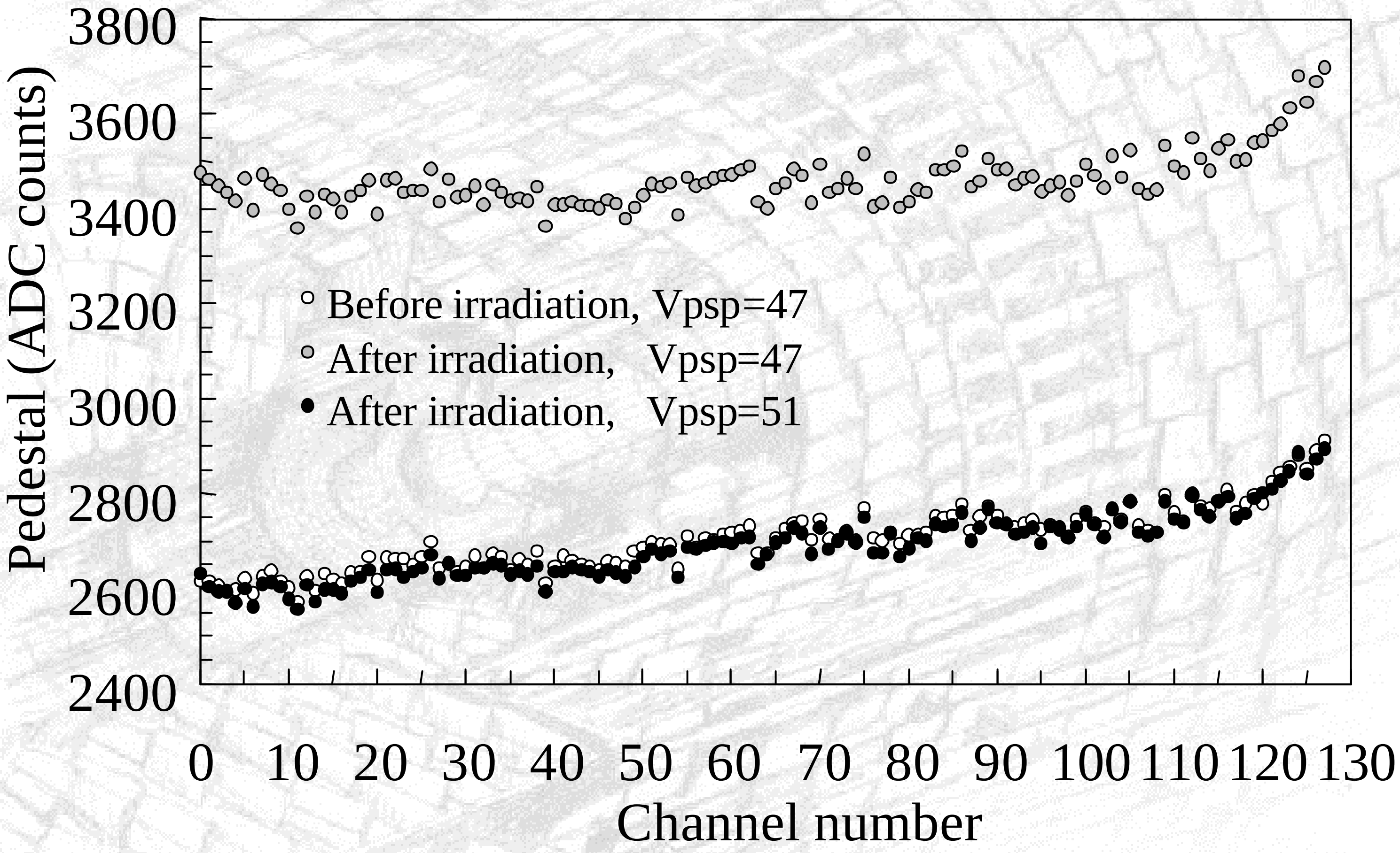
Chip after exposition of 80 Mrad with 10 MeV/c electron beam changes only some parameters, which could be adjusted by reloading new ones.



PD

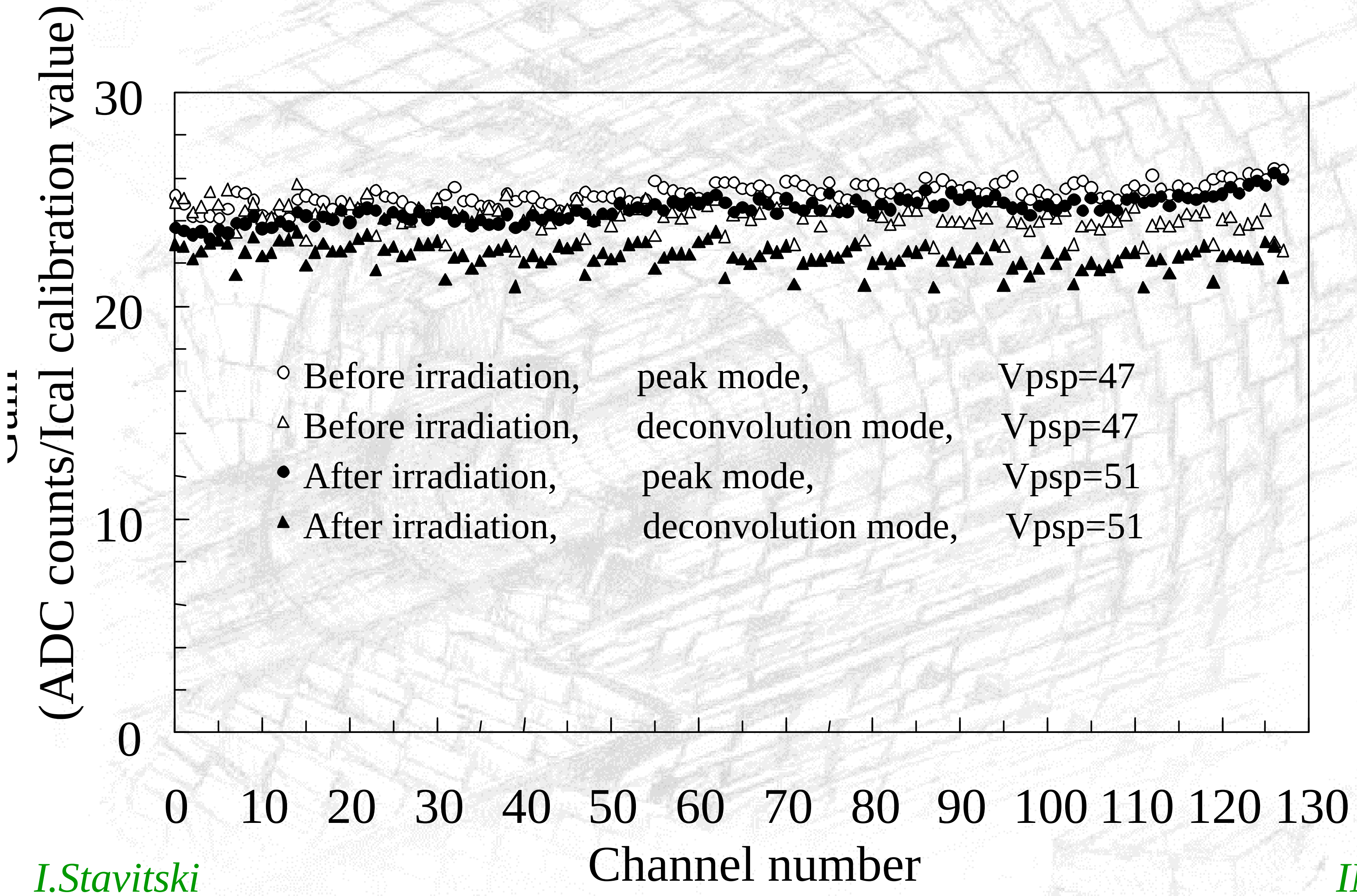
APV25 - test of radhardness

After 20 Mrad with 8 MeV/c electron beam pedestals are shifted, new parameter should be found to turn back.

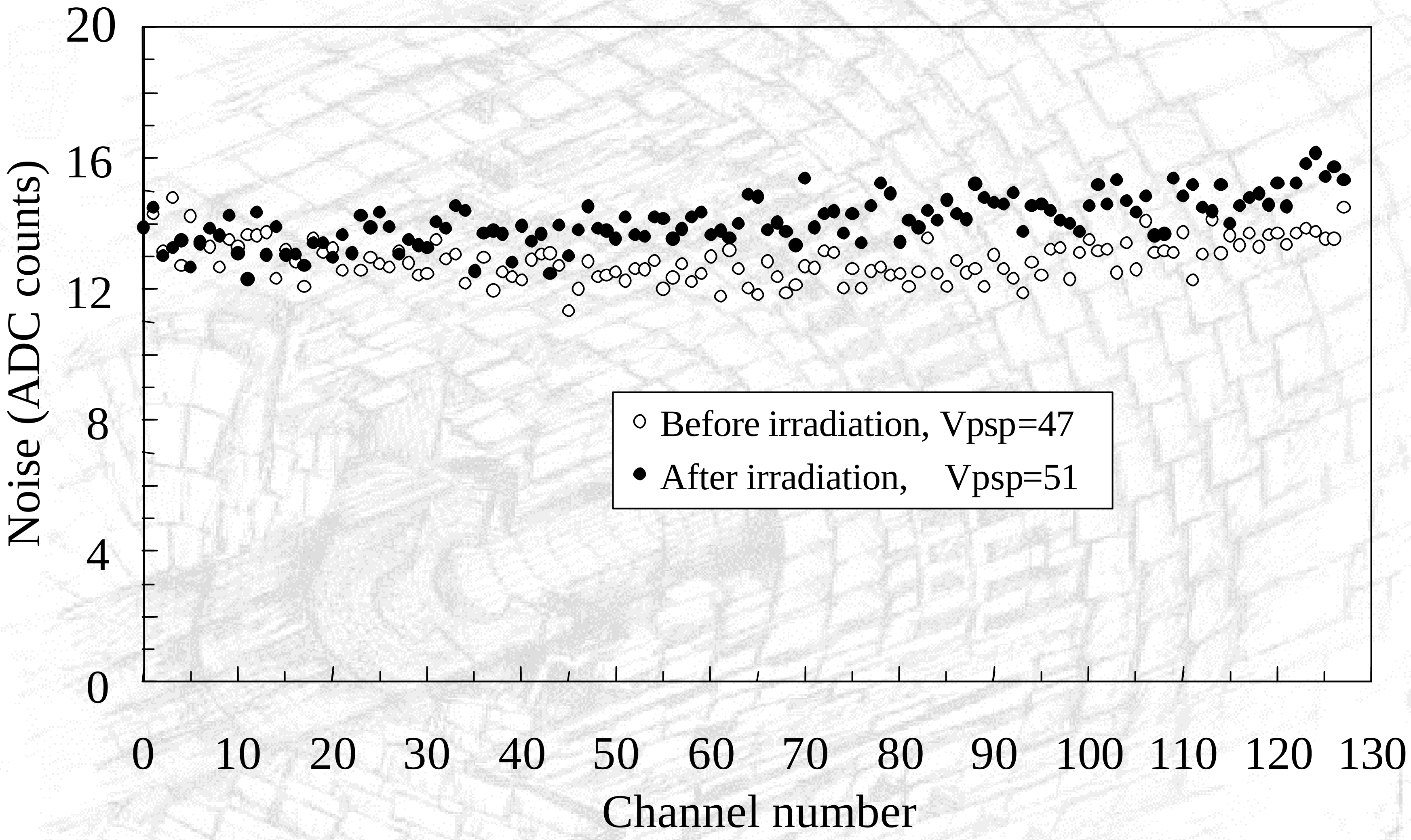


APV25 - test of radhardness

But gain and noise with new parameters doesn’t change too much...

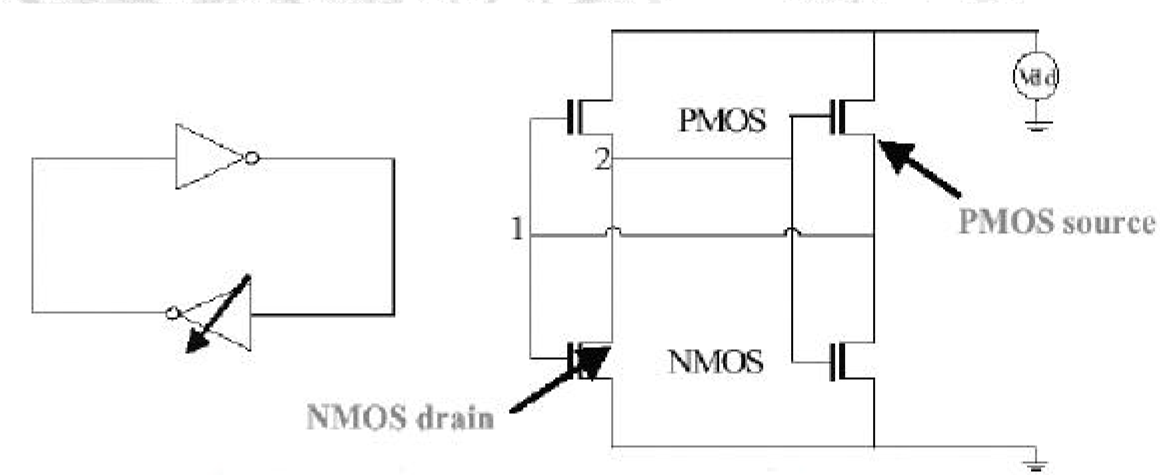


APV25 - test of radhardness



Single Event Upset of APV25

MIPs don't create problems for electronics, but highly ionising particle near sensitive circuit node can change state of logic elements. Exists probability of knock-on silicon ions in chip



4 APV25s in three tests were used at SiRad facility at Legnaro laboratory.

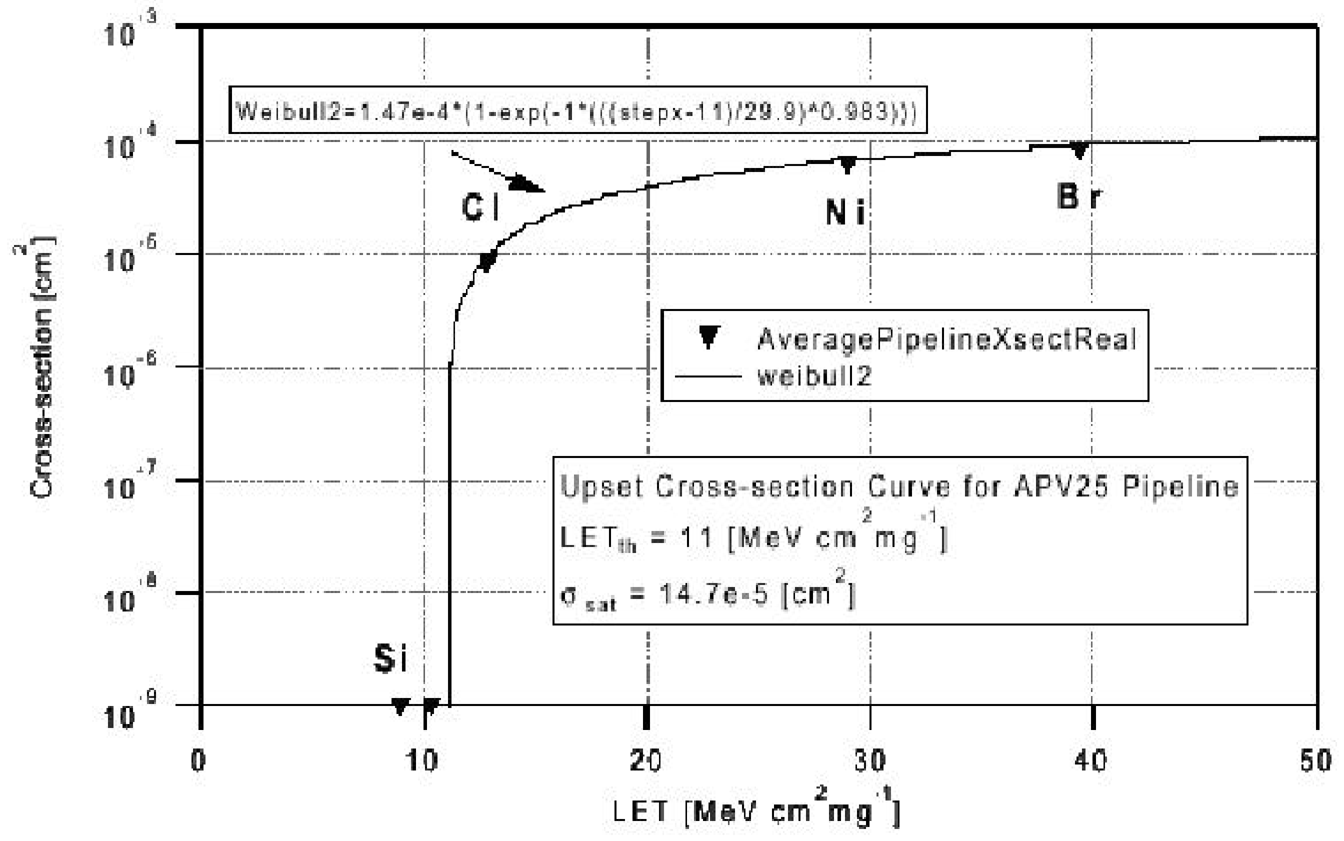
Ion	Si	Cl	Ti	Ni	Br	I
LET (MeV.cm^2.mg^{-1})	9-10	13-16	20-23	28-32	39	62

Used technique:
TANDEM with set of heavy ions; masking the different parts of chips.

Single Event Upset of APV25

Cross section is measured as

$$\sigma = \frac{N_{ev}}{\Phi}$$

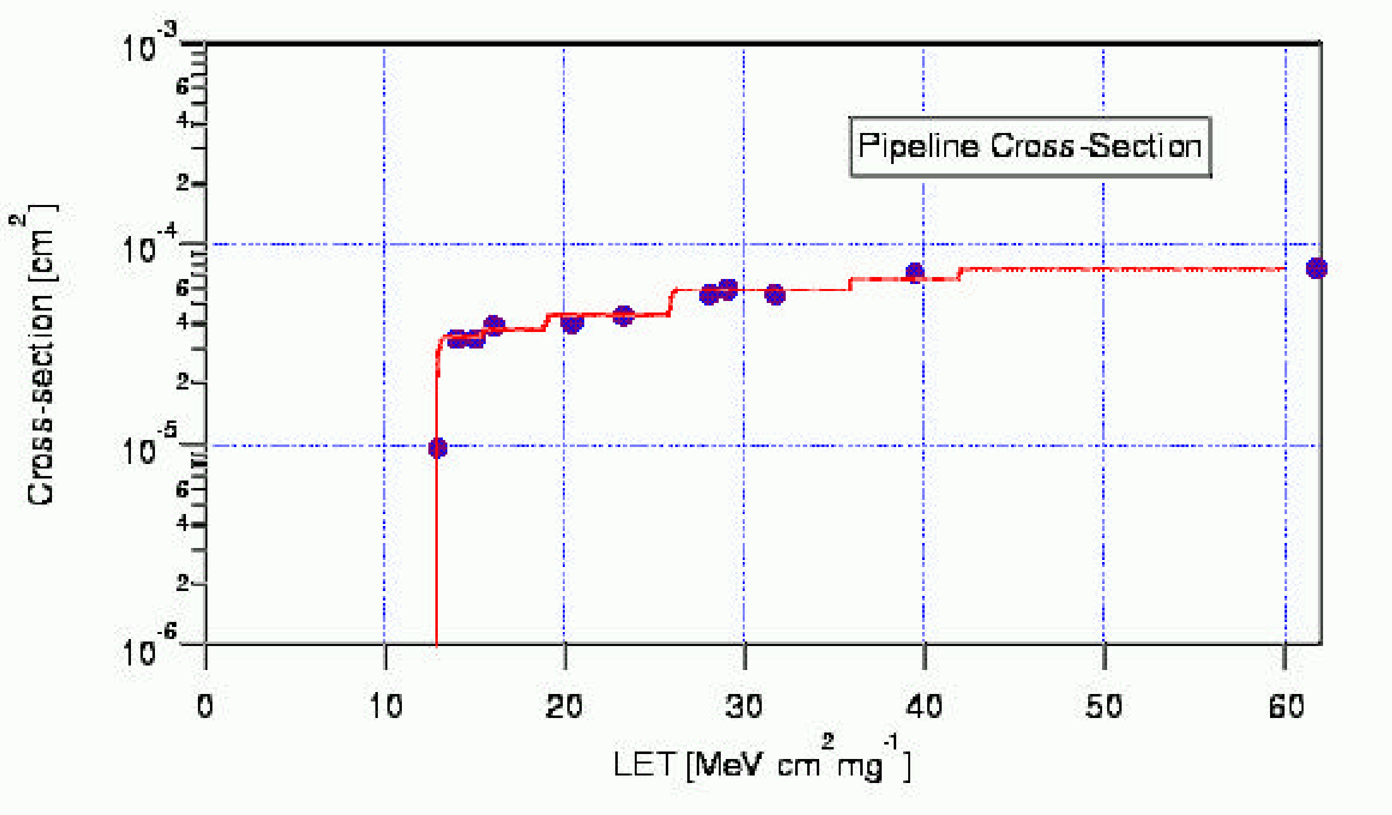


Single Event Upset of APV25

Final results :
$\sigma < 10^{-4}$ cm^2

implying
1 SEU event per
30 sec in the whole
tracker in worst case
= 0.15 % of all APV25
in 1 hour.

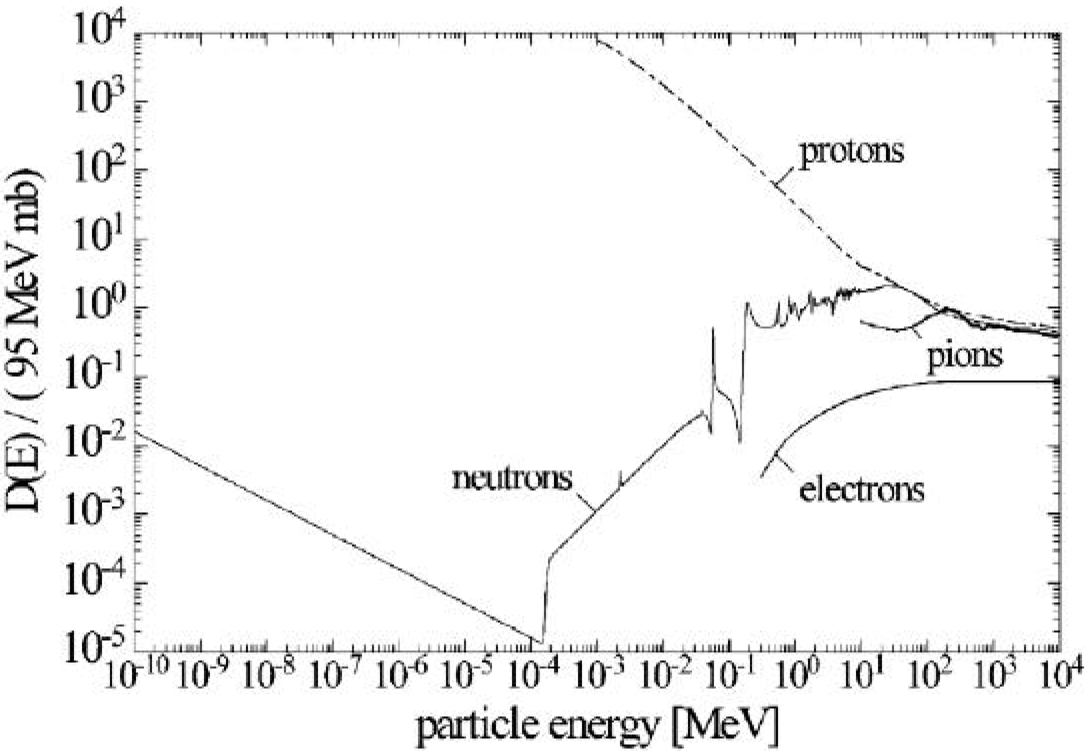
Result was verified
at the online
irradiation test with
350 MeV/c π beam.



Radiation effects

Non ionising energy loss
(NIEL)
introduction rate of defects is linear with fluence.

Complexity : depend on
- particle's type
- energy
- impurities present in Si
- postirradiation treatment



Important : energy transferred to the atom.
Threshold to remove Si from the lattice ~15 eV

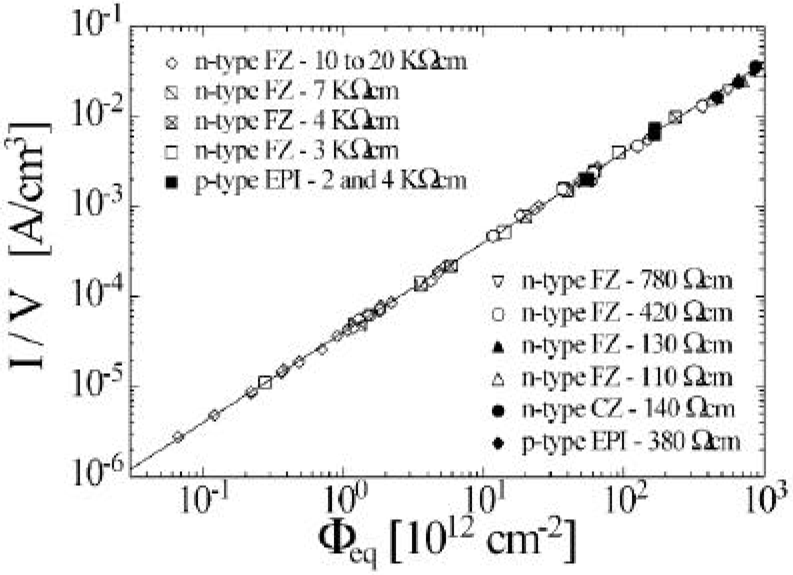
Gamma and electrons - 150 eV - produce point defects
neutrons 50 keV - clusters over 600 A
protons (high energy) - - clusters majority
(low energy) - - point defects (major introduction rate)

α and β of irradiation

$$\Delta I = \alpha\,[A/cm] \cdot \Phi_{eq}\,[cm^{-2}] \cdot Vol[cm^3]$$

$$\alpha = 4 \cdot 10^{17}\ A/cm$$

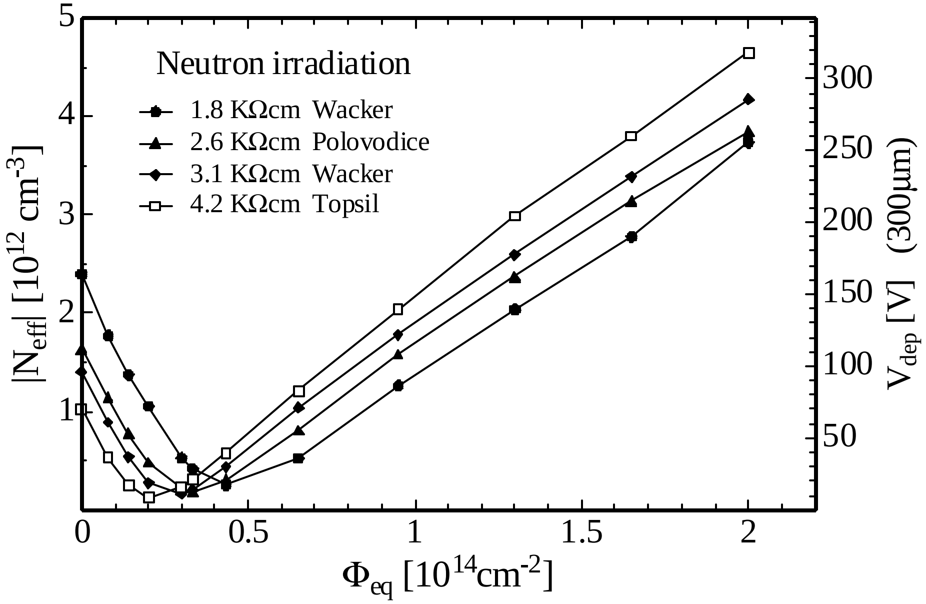
almost independent on resistivity



$$\Delta N_{eff}(\Phi_{eq}) = N_{eff0} \cdot \exp(-c\cdot\Phi_{eq}) + \beta\cdot\Phi_{eq}$$

donor removing

acceptor introduction



$$|N_{eff}| = 2\varepsilon_{Si} V_{dep} /(e\, d^2) \approx$$

$$\approx 1.45 \times 10^{10}\, V_{dep}\ \text{(for 300 µm Si)}$$

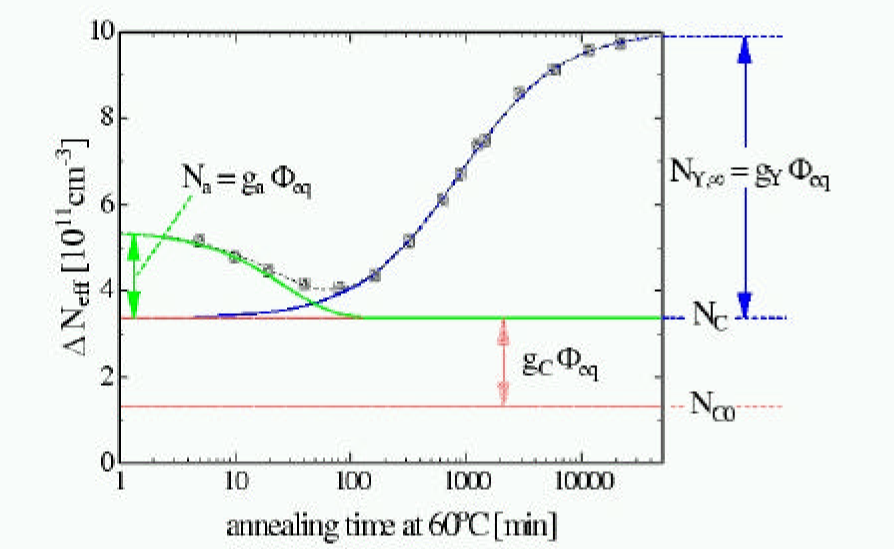
Post irradiation

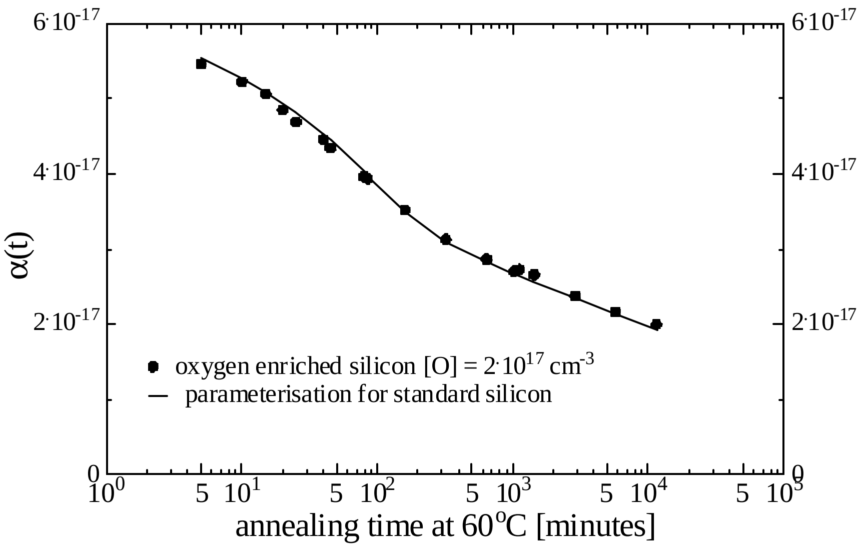
During irradiation two kind of defects are produced in the crystal lattice - vacancies (V) and interstitials (I) atoms.

After irradiation they are drifting and coupling with impurities present in Si - annealing process.

Mainly four defects are produced at the end:

VO_i
C_iC_s
C_iO_s
VV



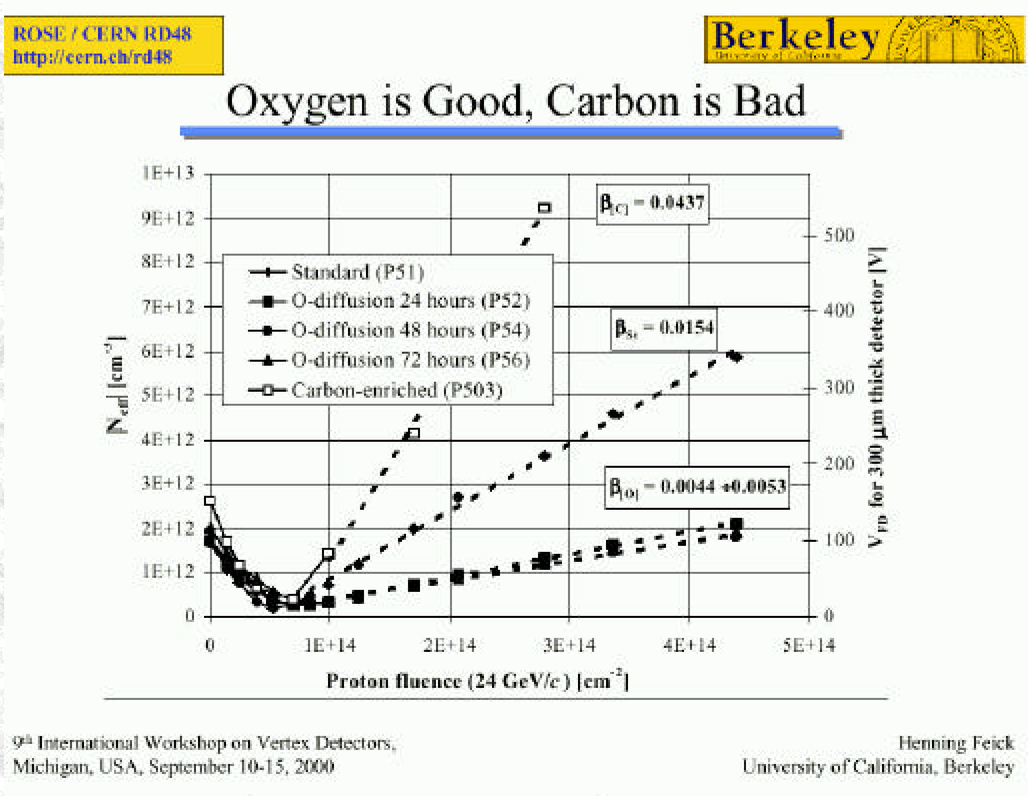


ROSE result

It is shown that oxygen enriched Si has lower acceptor introduction rate for charged particle fluences.

Effect is connected with higher rate of direct production of V_2O in the point defects, produced by charged particles.

No effect for neutron irradiation, and no influence for α !



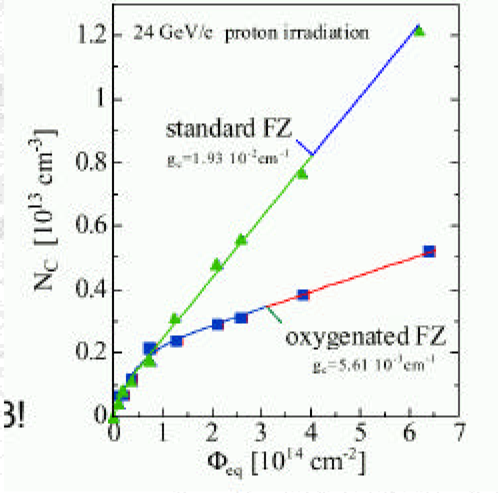
ROSE / CERN RD48
http://cern.ch/rd48

Berkeley

Oxygen is Good, Carbon is Bad

9th International Workshop on Vertex Detectors,
Michigan, USA, September 10-15, 2000

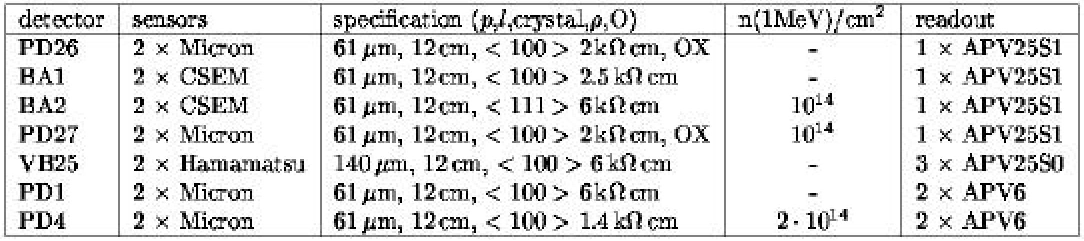
Henning Feick
University of California, Berkeley



Test on the beam

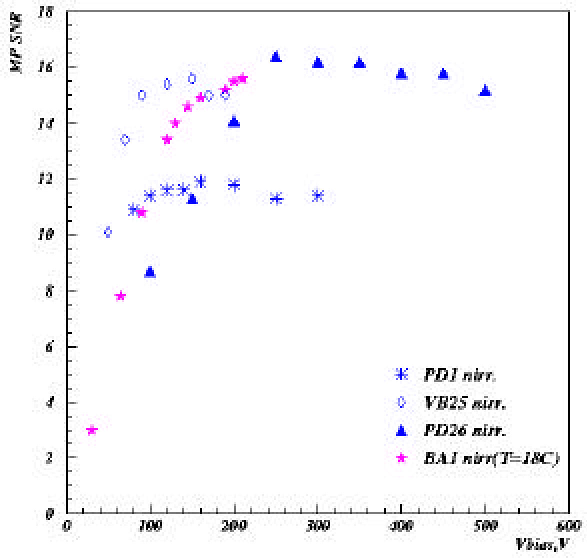
Beam test with some detectors was performed in order to verify the benefit of oxygenation.

Unfortunately the result is obscured by the technological details.

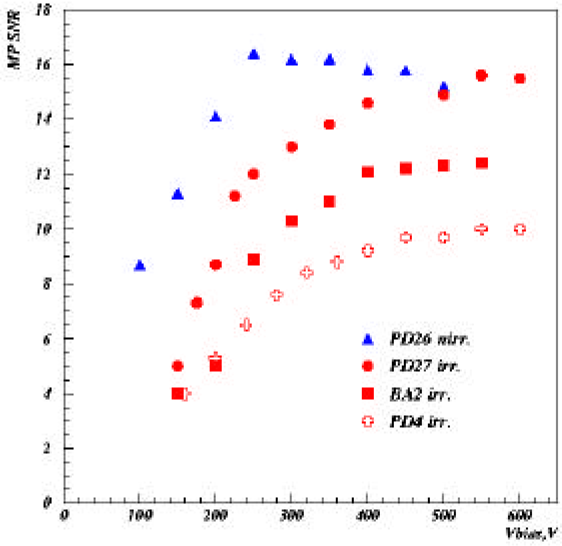


detector	sensors	specification (p,l,crystal,ρ,O)	n(1MeV)/cm^2	readout
PD26	2 × Micron	61 μm, 12 cm, $< 100 >$ 2 kΩ cm, OX	-	1 × APV25S1
BA1	2 × CSEM	61 μm, 12 cm, $< 100 >$ 2.5 kΩ cm	-	1 × APV25S1
BA2	2 × CSEM	61 μm, 12 cm, $< 111 >$ 6 kΩ cm	10^{14}	1 × APV25S1
PD27	2 × Micron	61 μm, 12 cm, $< 100 >$ 2 kΩ cm, OX	10^{14}	1 × APV25S1
VB25	2 × Hamamatsu	140 μm, 12 cm, $< 100 >$ 6 kΩ cm	-	3 × APV25S0
PD1	2 × Micron	61 μm, 12 cm, $< 100 >$ 6 kΩ cm	-	2 × APV6
PD4	2 × Micron	61 μm, 12 cm, $< 100 >$ 1.4 kΩ cm	$2 \cdot 10^{14}$	2 × APV6

Non irradiated



irradiated



CCE with laser

2 detectors – oxygenated and standard silicon strip detectors, produced by MICRON Semiconductors (UK)

diffused oxygenation, 1150 ^{o}C, 110 h,

[O] = 2.5 x 10^{17} cm^{-3}

production for L00 CDF –

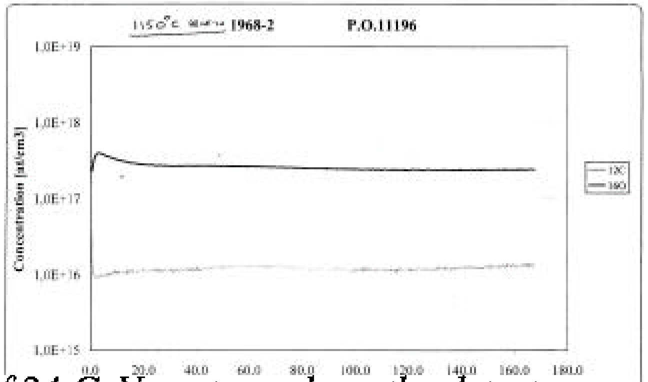
128 strips,

50 um pitch ,

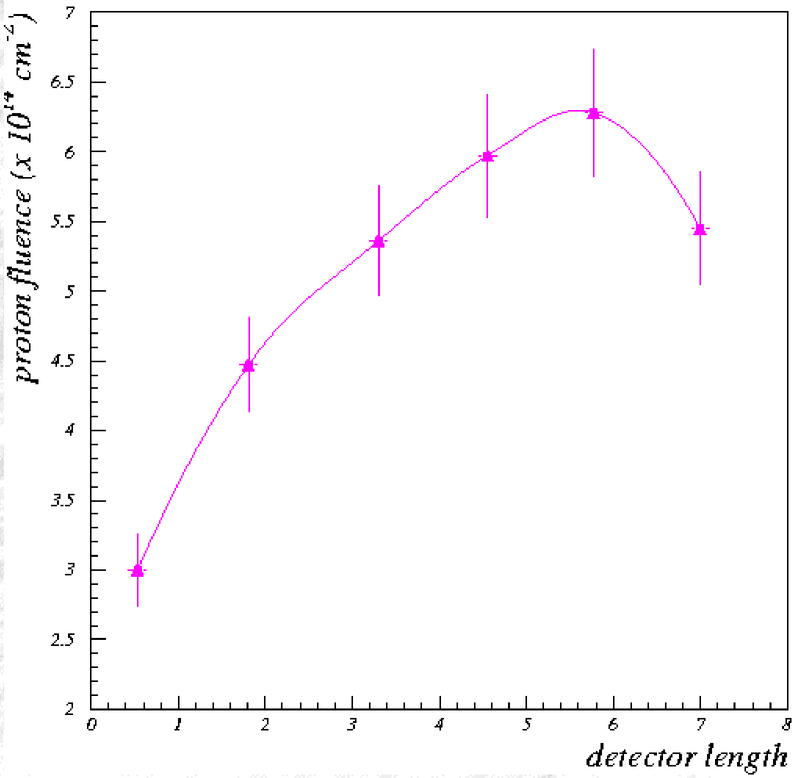
7.5 cm length

Vdep = 90 V (O) and

18 V (S)



Fluence of 24 GeV protons along the detectors



Irradiation by 24 GeV protons

fluence 3-6.5 • 10^{14} cm^{-2}

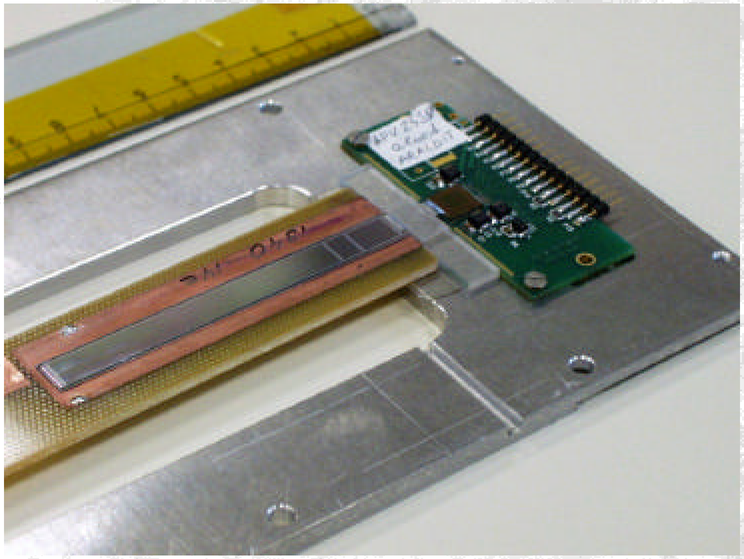
measured by activation analysis.

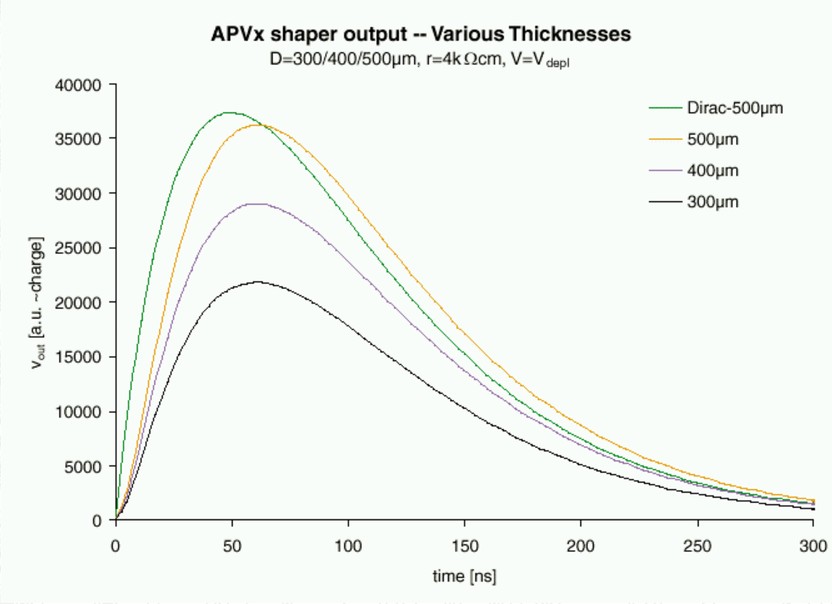
Annealing at room temperature 1 week.

CCE

Detectors were connected with prototype
of FE chip of CMS Si Tracker, $t_p = 50$ ns
in order to perform the data acquisition.

The signal is expected to be linear with depletion depth.





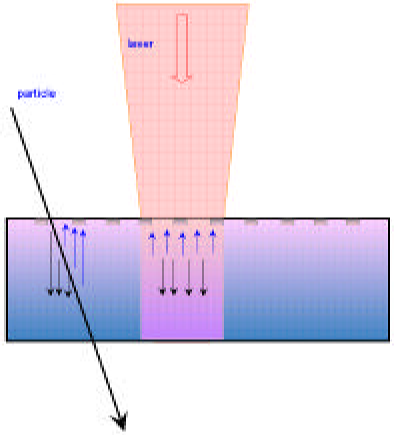
T.Bauer et al., NIM A461 (2001) 192

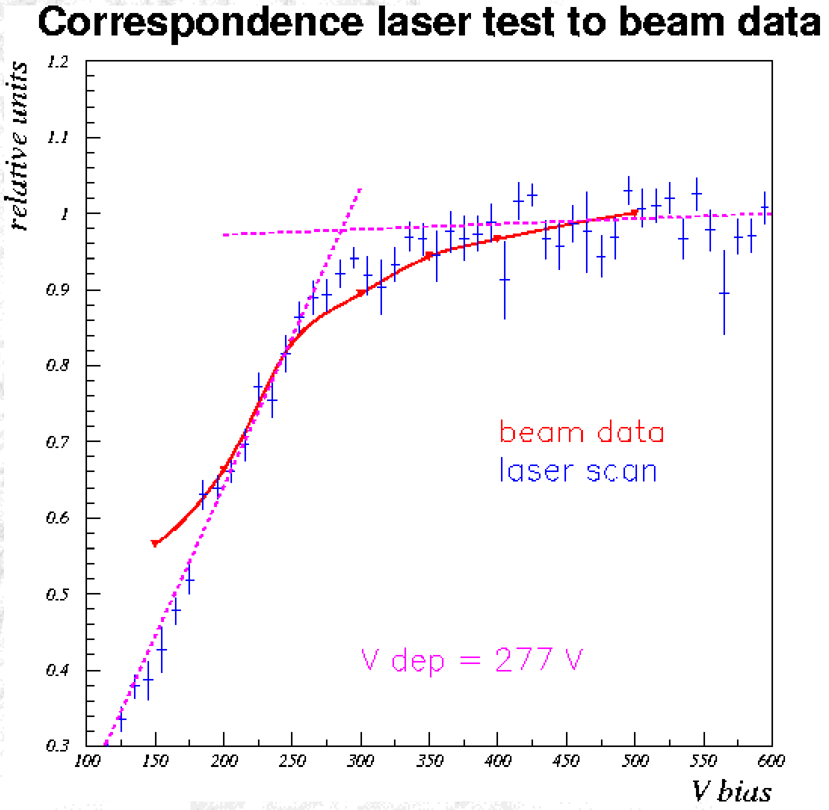
CCE -setup

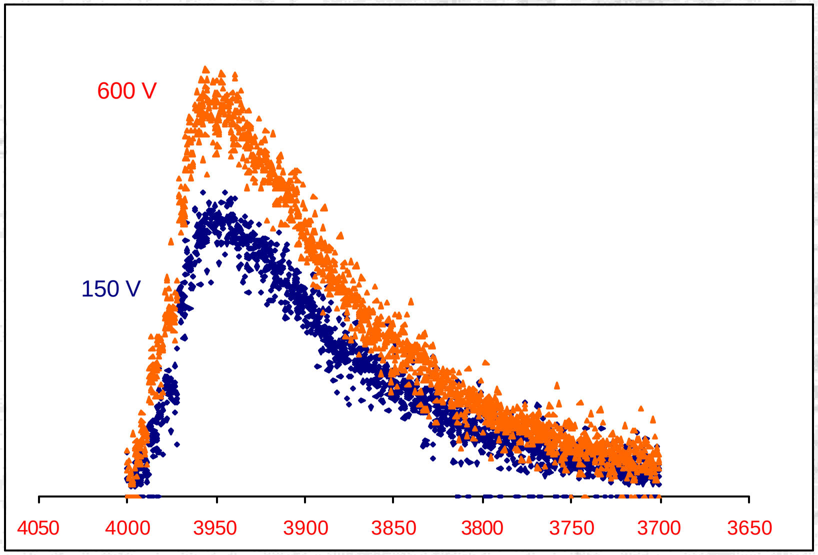
Laser beam of 1060 nm wavelength was spread between few strips and scan the CCE curve along the strips.

Good agreement with particle beam data.

Better defined point of the full depletion voltage, no timing shift.




Correspondence laser test to beam data

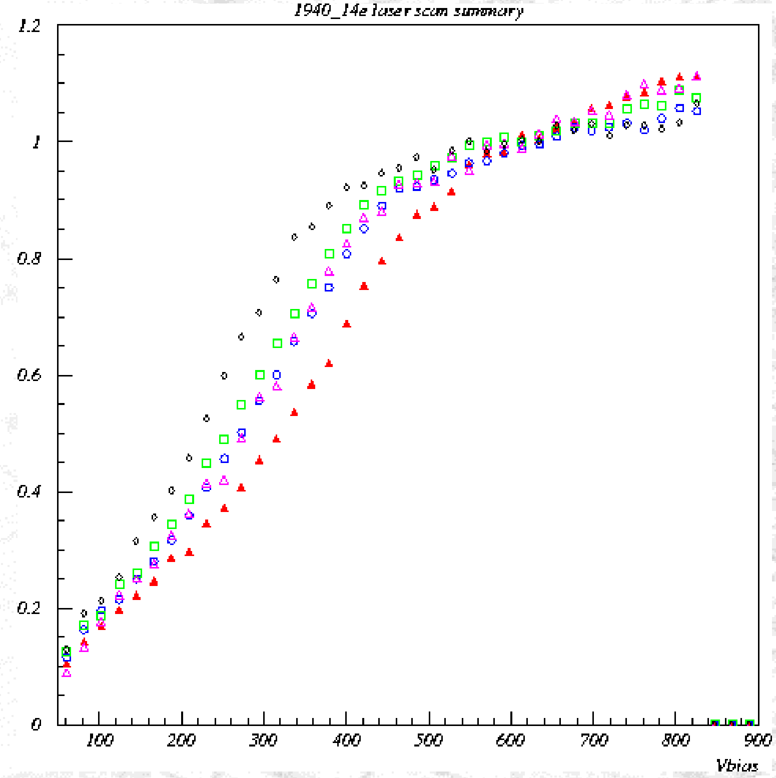


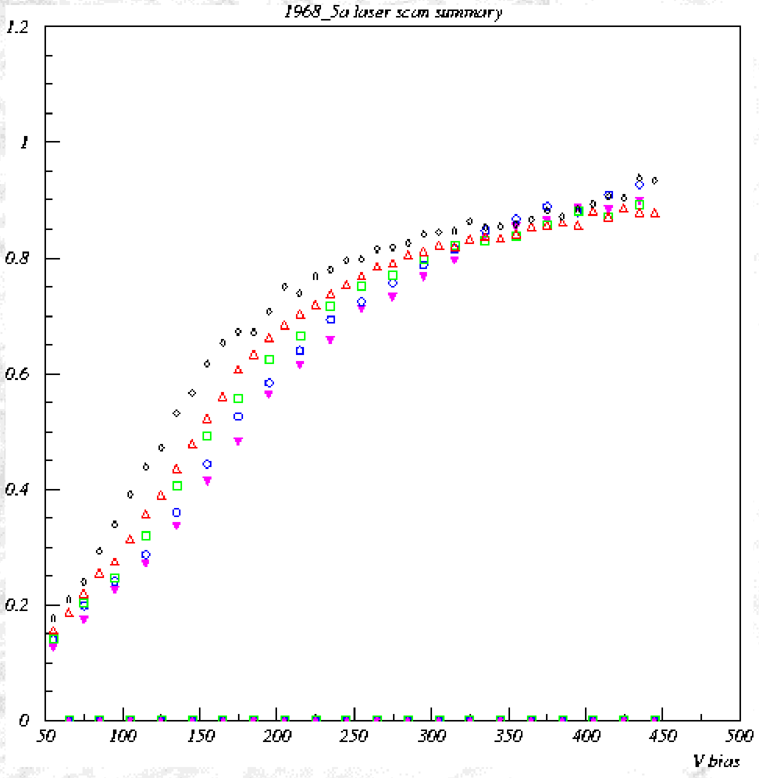
CCE-signal

The CCE increases after depletion, particulary for highly irradiated standard detector.

standard

oxygenated



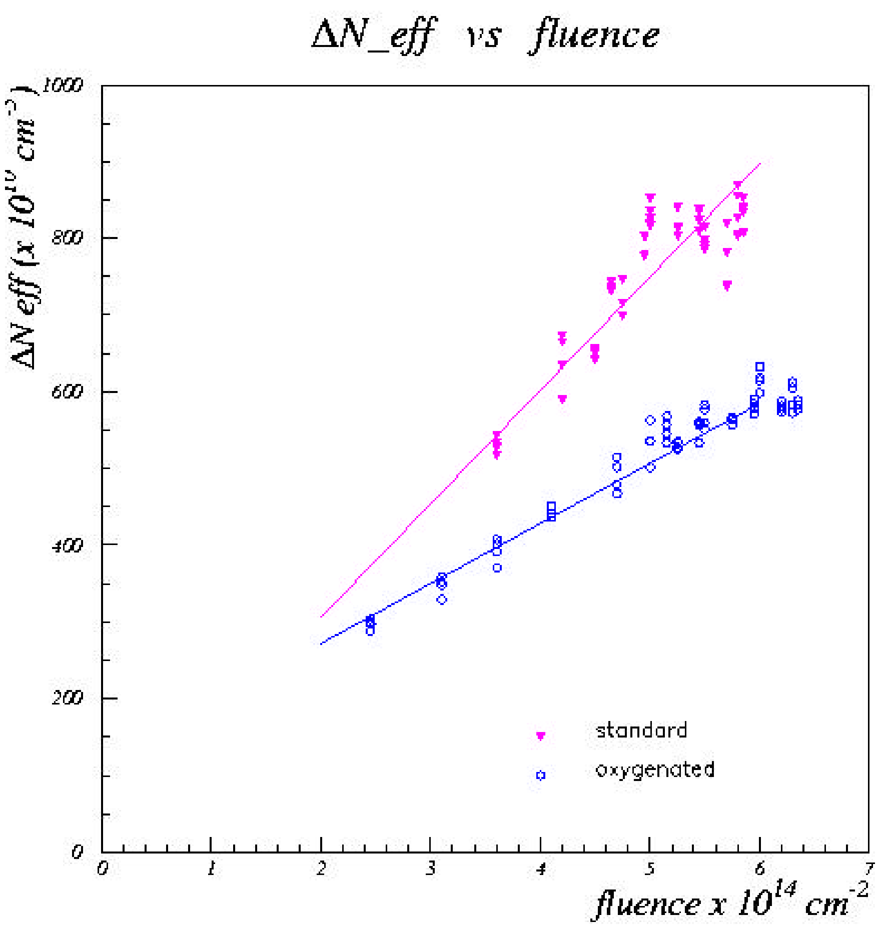


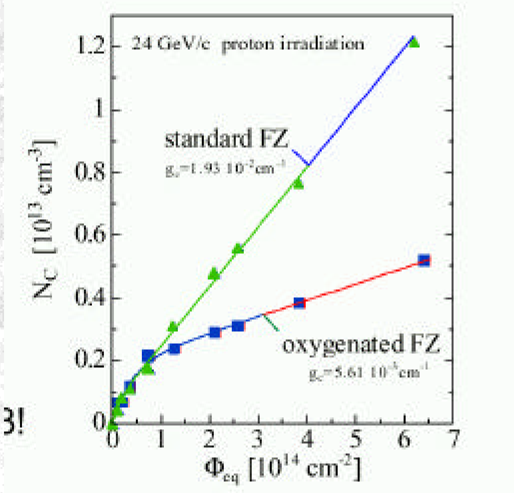
CCE-results

Difference between standard and oxygenated detector is not negligible, but effect is lower than expected from CV measurements of diodes:

β of detectors and diodes

St	14.8	13.6	×10^{-3} cm^{-1}
Oxy	7.8	3.5	×10^{-3} cm^{-1}

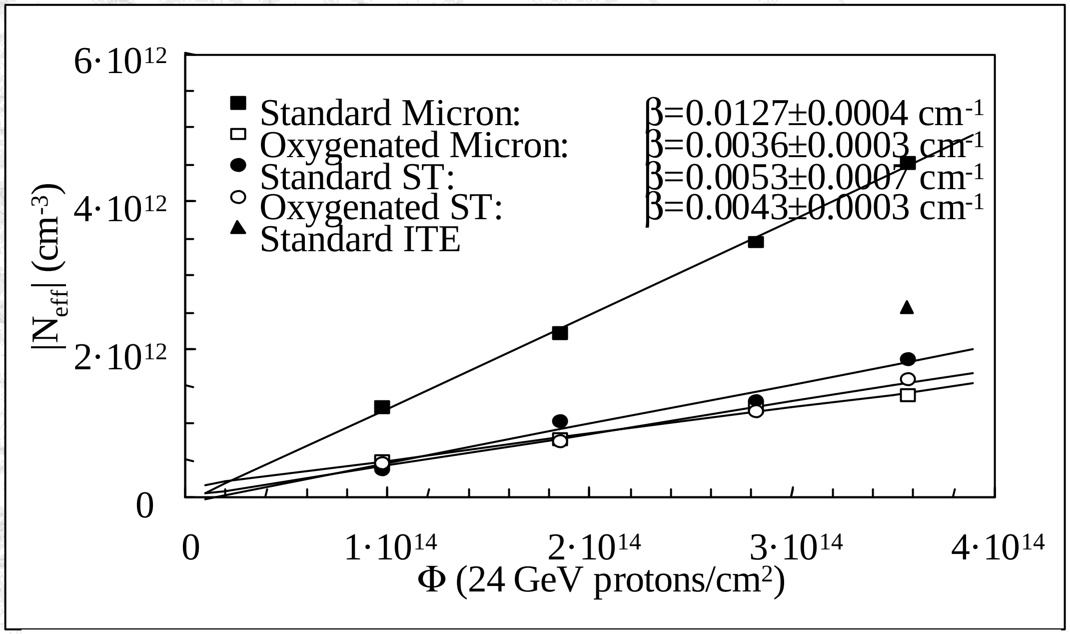


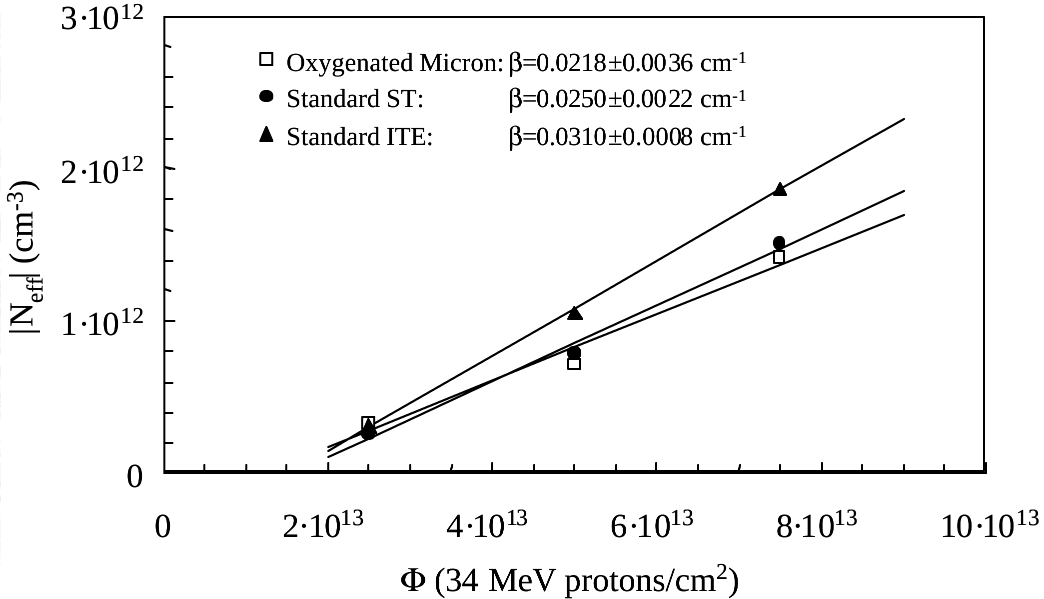


Last news

Diodes produced by ST (Catania) on the standard substrate show behavior of oxygenated ones.

Were irradiated by 24 GeV and 34 MeV protons.





Even more

ST diodes shows higher radiation hardness after neutron irradiation !