The MAD

BiCMOS FRONTEND ASIC
FOR THE READOUT
OF THE DRIFT TUBES OF
CMS BARREL MUON DETECTOR

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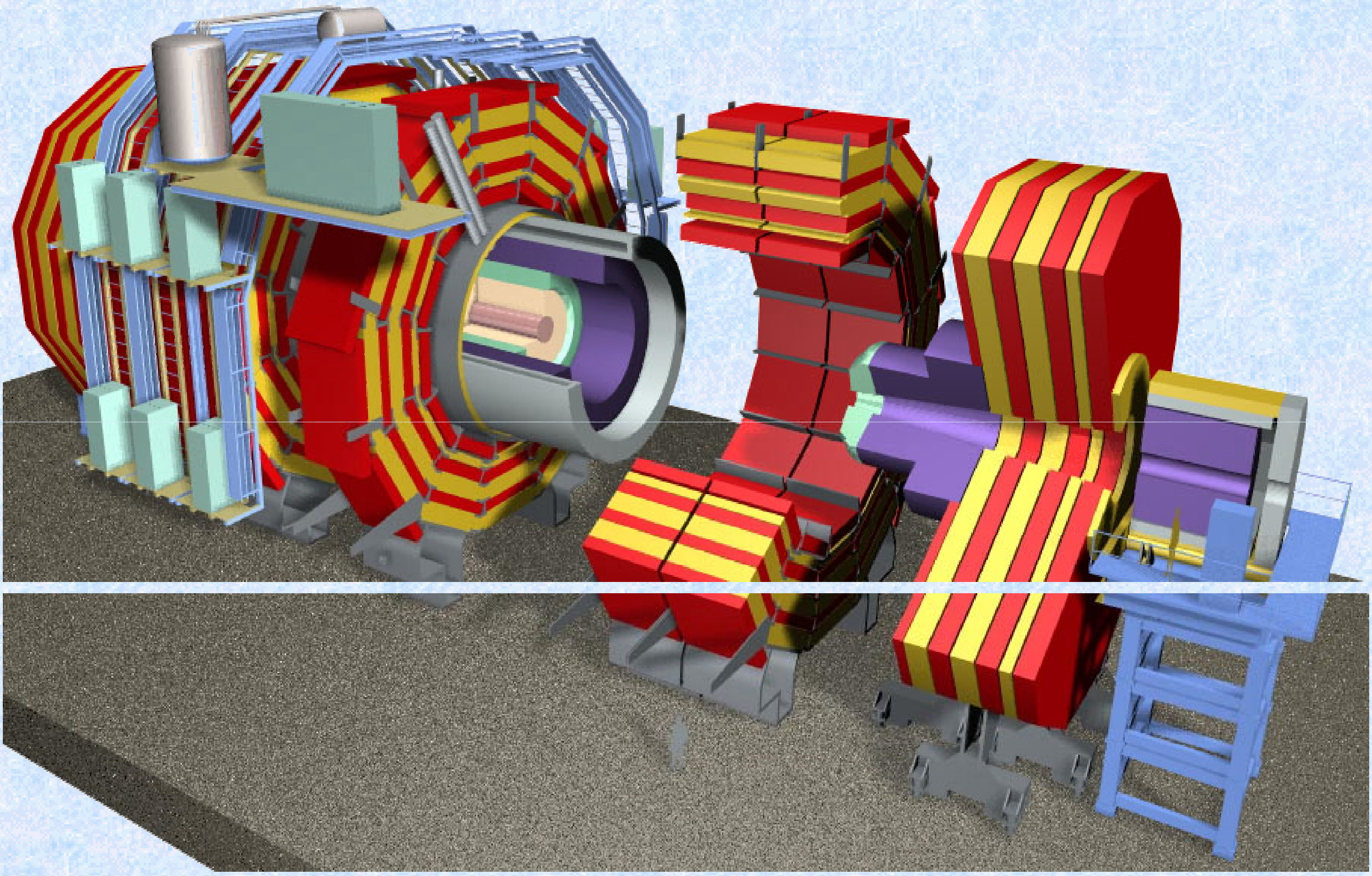
SIF - Pavia 1999

Compact Muon Solenoid

CMS is a general purpose proton-proton detector designed to run at the highest luminosity at the LHC (Large Hadron Collider).

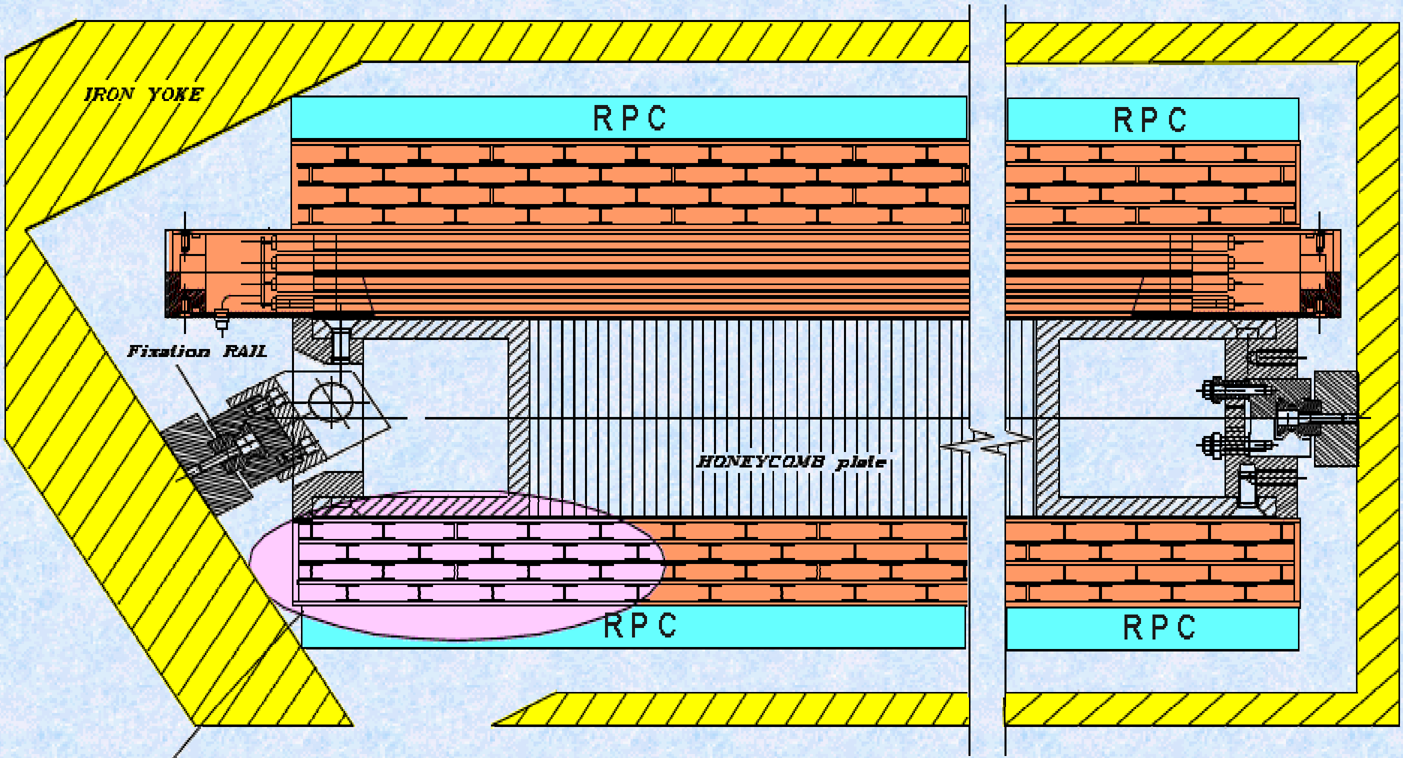


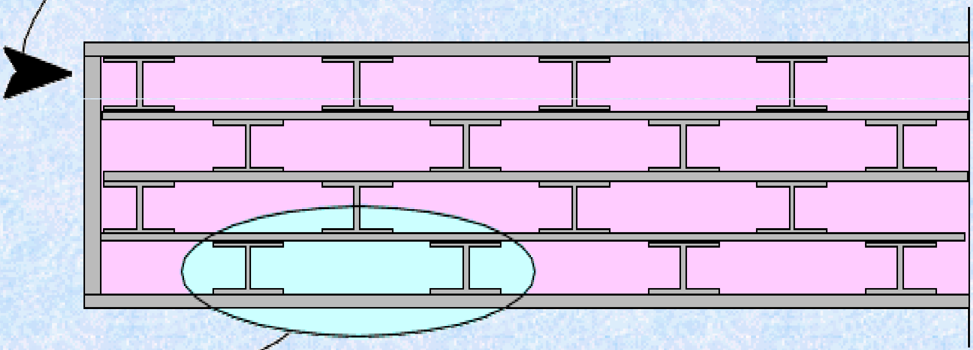
The main design goals of CMS are:

i) a highly performant **muon system**
ii) the best possible **electromagnetic calorimeter** consistent with (i)
iii) a high quality **central tracking** to achieve i) and ii)
iv) hermetic **hadron calorimeter**

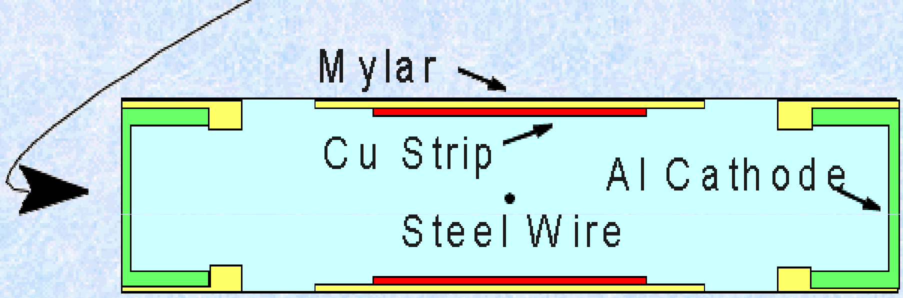
Barrel Muon Chamber

3 Superlayers per chamber





4 layers of drift tubes per superlayer



cell of 4.2 × 1.1 cm^2

Detector Parameters
&
Frontend Design

- **Gas mixture $ArCO_2$ 85:15 @ atmospheric pressure**
- **Expected rate: 10 Hz/cm^2**
- **Drift rate 55 μm/ns; max drift time 400 ns**
- **Low gain (50 k - 100 k) for long lifetime**
- **Maximum tube length 3 m; ϕ wires 50 μm**

Main goals are efficiency & time resolution

The frontend task is to amplify signals, discriminate them against an external threshold and transmit the results to data acquisition. This must be accomplished in the smallest space and consuming very little power in order to maximize detector active volume and reduce service costs.

- Low noise, high gain analog chain.
- Fast rise time to minimize time walk due to different amplitude signals from drift tubes.
- Maximum uniformity among chips without equalization at wafer or board level. Hence low offsets and little tolerance for gain.
- Built in hysteresis to improve speed and stability.
- Programmable output width independent from signal amplitude to override cable bandwidth.
- Fast, low level (LVDS compatible) cable driver to minimize power and interferences.
- Other features for control & monitor purposes like the possibility of masking noisy channels and inclusion of a temperature sensor.

MAD Front End Chip

Development History

1995 — **MAD**

First prototype: preamplifier, comparator and output driver
1.2u BiCMOS Tech.

1997 — **MADII**

2 complete electronic chains
0.8u BiCMOS Tech.

1998 — **NEWMAD**

4 complete electronic chains
0.8u BiCMOS Tech.

1998 — **MADAUX**

Prototype to test auxiliary circuits: masks and T probe
0.8u BiCMOS Tech.

1998 — **MAD4**

4 complete electronic chains with temperature probe
0.8u BiCMOS Tech.

Nearly 200 pieces produced for chamber equipping

1999 — **TRIMAD**

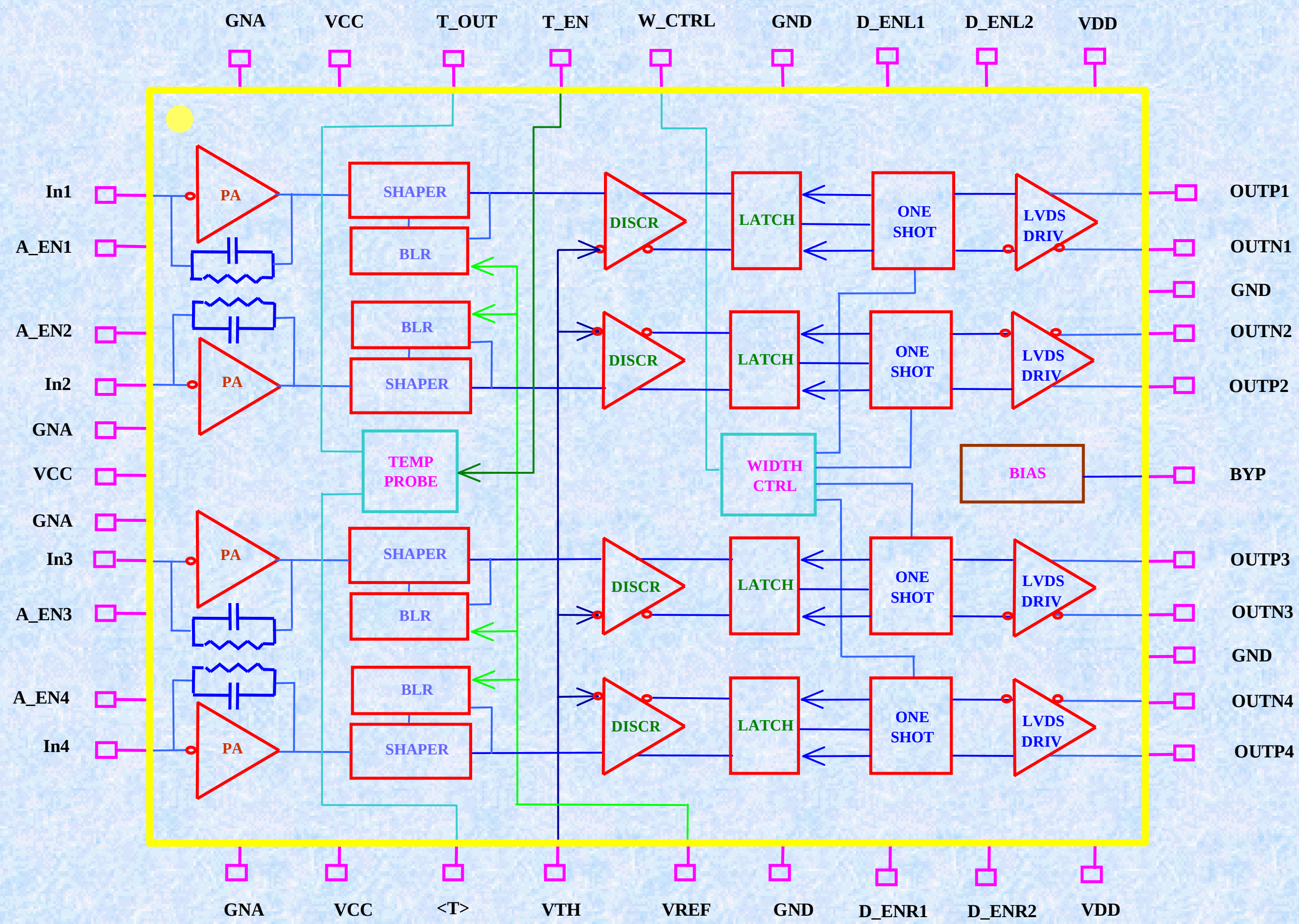
3 complete electronic chains to test preamplifier and masking
0.8u BiCMOS Tech.

1999 — **The MAD**

Front End Chip on TQFP 44
FINAL VERSION
0.8u BiCMOS Tech.

MAD Front End Chip

Block diagram and Pinouts



PIN	Meaning	Notes
GNA	Analog ground	-
GND	Digital ground	-
VCC	+5V power supply	Capacitor of 100nF to ground
VDD	+2.5V power supply	Capacitor of 100nF to ground
BYP	Internal reference voltage output	Capacitor of 100nF to ground
VTH	Threshold voltage	VRIF + threshold (3mV/fC)
VREF	Signal reference baseline voltage	Usually 1.5V
In(1-4)	4 input channels	-
T_OUT	Temperature probe output, externally enabled with pin T_EN	About 7.5mV/°K
<T>	Temperature probe output	About 7.5mV/°K
T_EN	T_OUT enable (logic level high, internally pull up)	TTL level
A_EN(1-4)	4 analog masks enable: logic level high, internally pull down	TTL level
D_ENR(1,2)	Digital right mask enable: D_ENR1 high, D_ENR2 low	High: 1.5-1.6 V Low: 1.2-1.3 V
D_ENL(1,2)	Digital left mask enable: D_ENL1 high, D_ENL2 low	High: 1.5-1.6 V Low: 1.2-1.3 V
W_CTRL	Output width control, common to all channels	Usually resistor to ground
OUTN(1-4) OUTP(1-4)	Differential output channel 1-4, LVDS compatible levels	120 Ohm terminating resistor

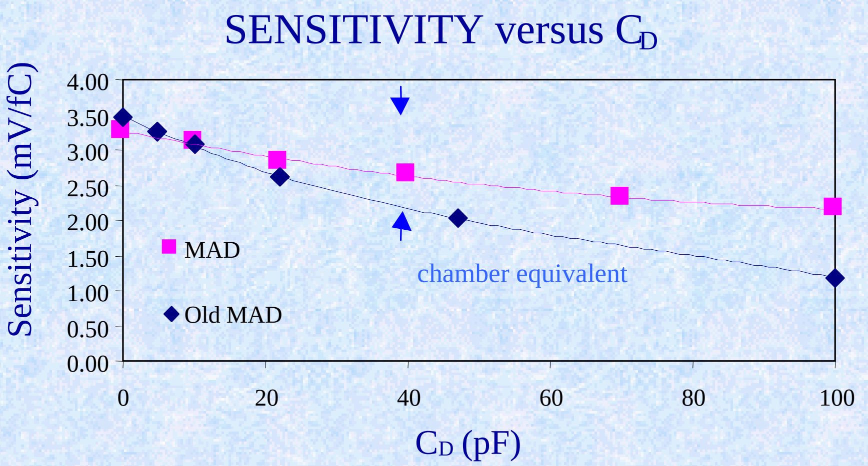
MAD Front End Chip

General Characteristics and Performances

- **O.8 μm BiCMOS** technology by AMS
- **4 channels in 2.5 x 2.5 mm^2 die area** housed in 44 pins TQFP case
- **25 mW/ch @ +5 V & +2.5 V**, minimal variation with signal rate and temperature
- **Simple shaper, with short integration time**, inside feedback loop of a low offset OTA
- **Low offset and hysteresis spread** < 0.13 fC r.m.s. total error
- **Baseline and threshold levels common** to all channels
- **max input rate** without accuracy loss **> 2 MHz @ 1 pC**
- **One shot activated latch** (dead time 9 ns)
- Voltage output with **LVDS compatible levels** (t_r & t_f < 2.5 ns); termination resistors inside pads
- **input crosstalk < 0.2%**
- External settable **output width between 20 ns and 200 ns** (5% r.m.s. @ 50 ns) almost independent from signal amplitude
- **temperature sensor**: 7.5 mV/ °K sensitivity, 3 °K max error @ 25 °C
- **fast and slow masking features** for chamber test and to disable noisy channels

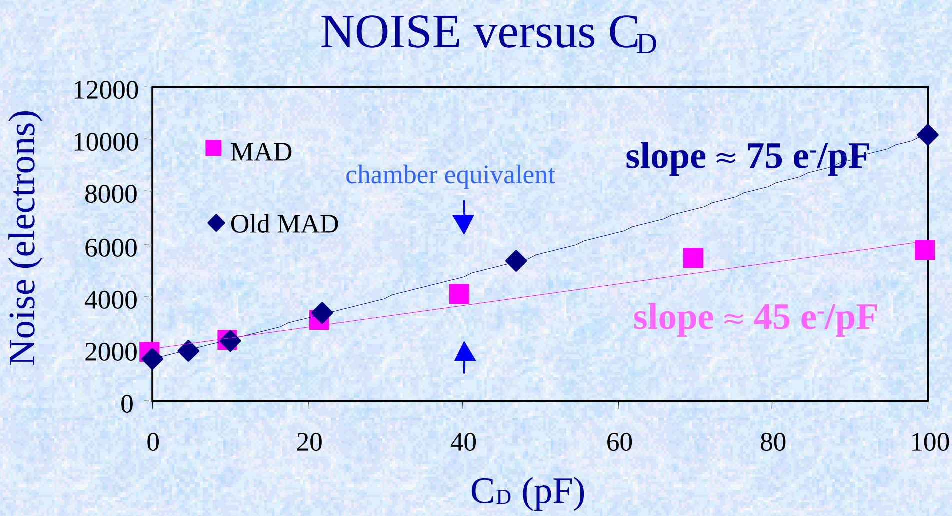
MAD Front End Chip

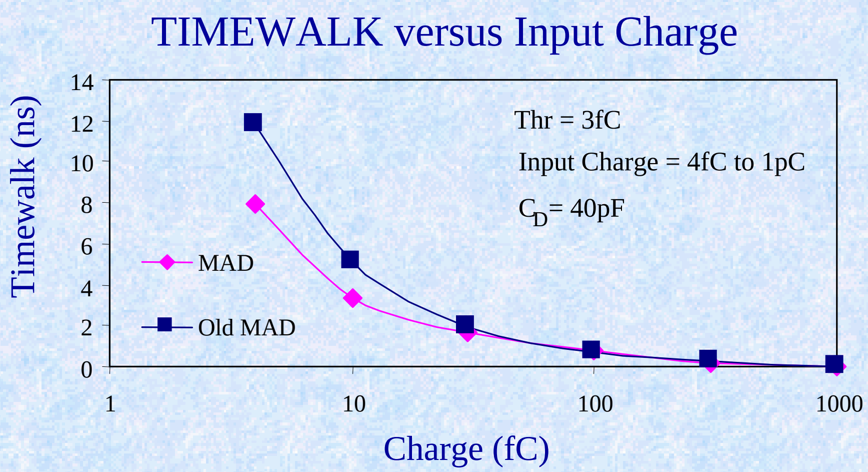
Sensitivity, Noise and Timewalk



Last version is compared with old one

Performances versus C_D are all improved





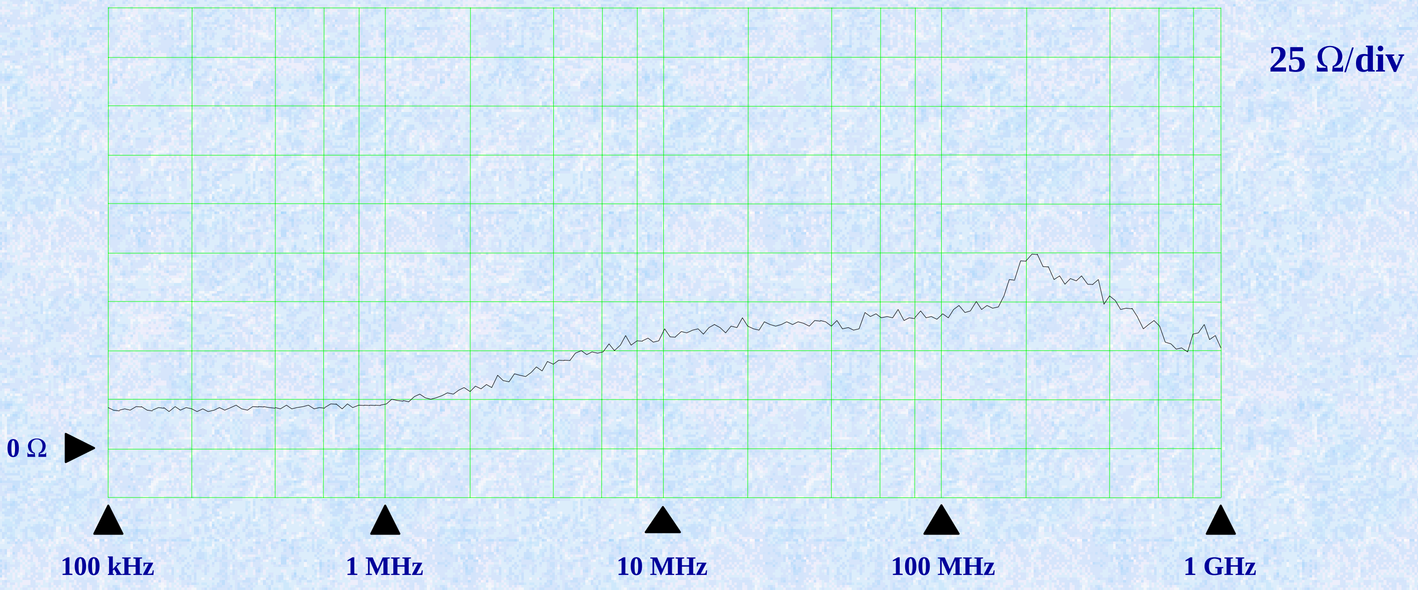
New version include full masking feature

All tests include stray capacitance (about 10 pF) of Front End Board

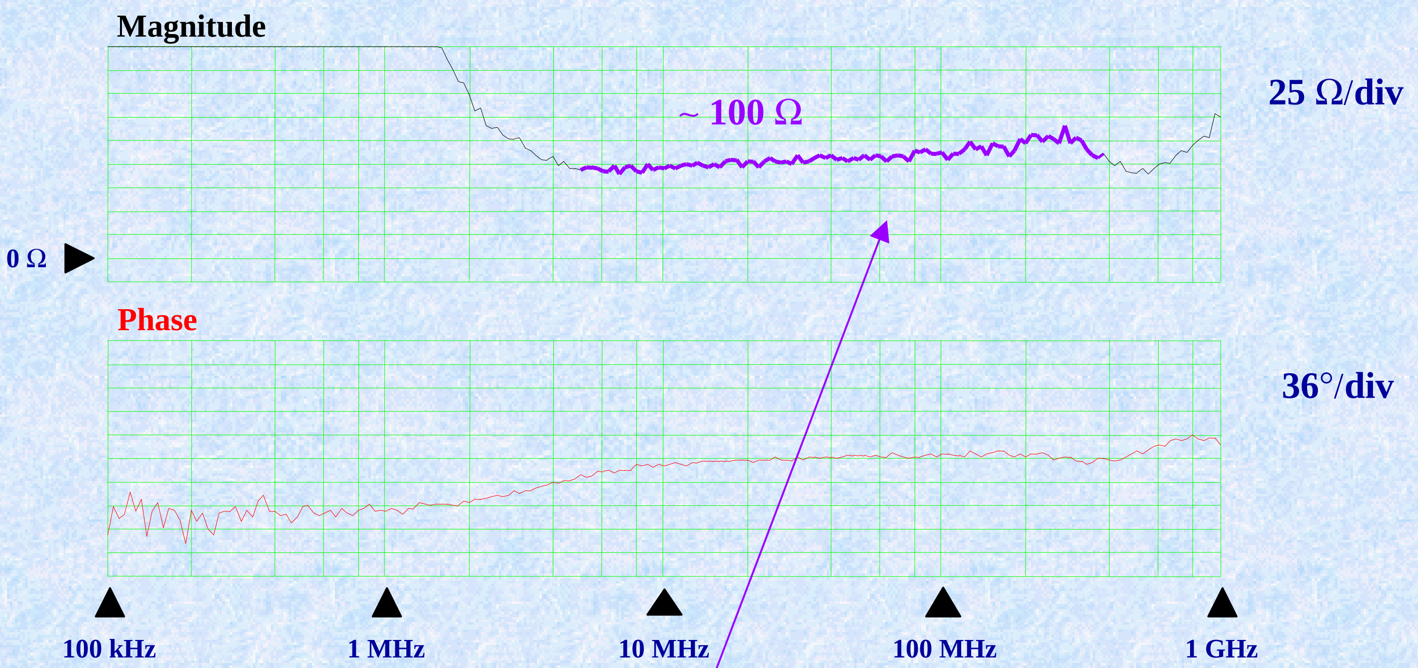
MAD Front End Chip

Input Impedance

Impedance with input pin disconnected from PCB

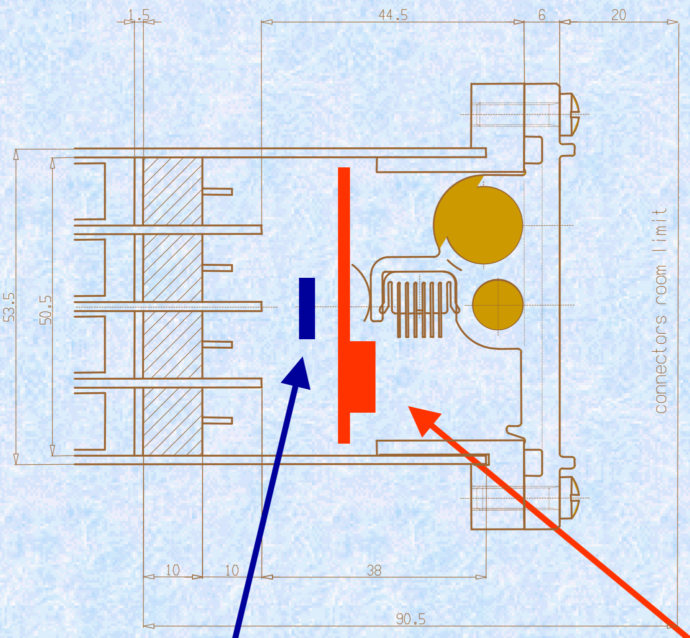


Impedance with series protection resistor (39 Ω) and HVCAP



Impedance seen by chamber is almost flat on r.o.i.

MAD Front End Board
(for MAD4 prototype)

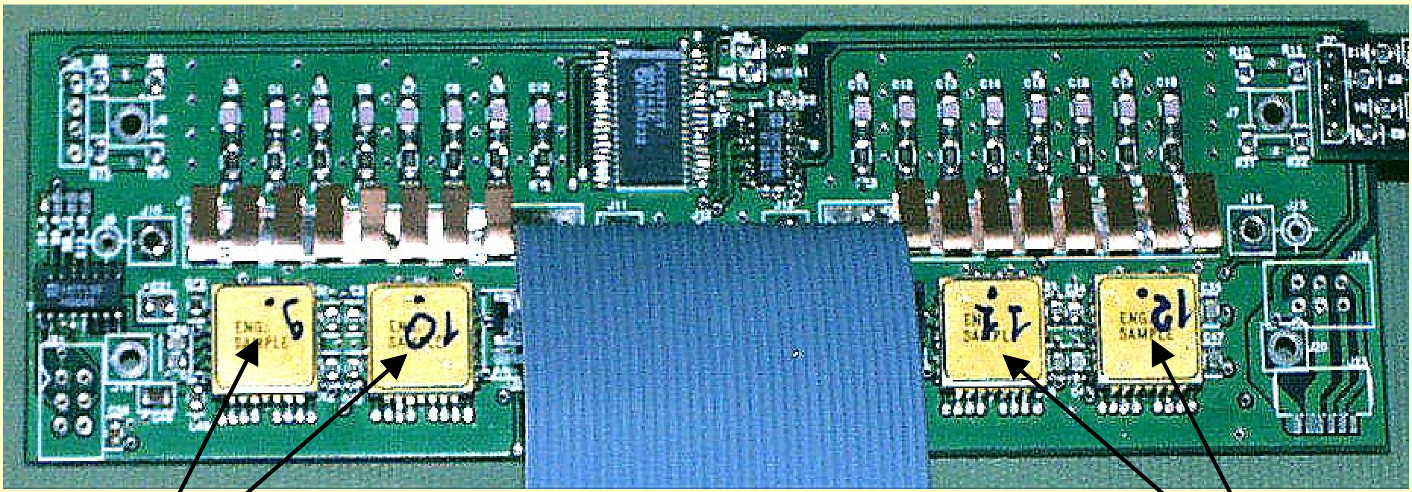


Chamber cross section

- **1 superlayer of MB96 chamber equipped (56 chips) for August 98 muon Test Beam**
- **Q4 superlayer fully equipped for July 99 muon Test Beam**

Cap Board

Front End Board



MAD

MAD

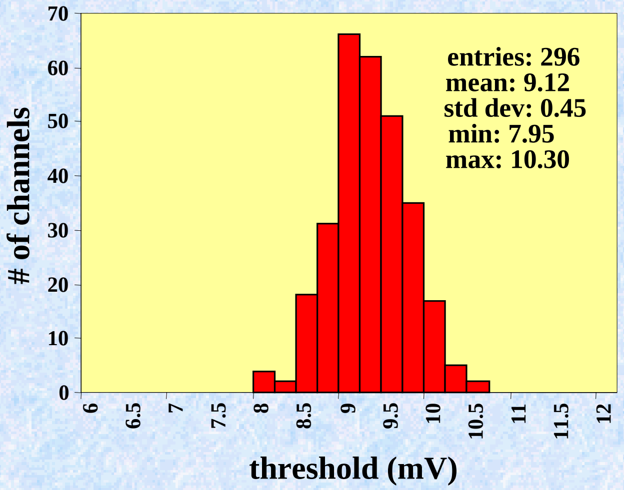
CHARACTERISTICS

- **16 channels**
- **155 x 45 mm^2; 4 layers**
- **I^{2}C interface for temperature readout & mask programming**
- **Double distribution of test pulse**
- **Additional protection diodes on inputs**
- **Total thickness (detector dead space) 20 mm (including input HV capacitor board)**

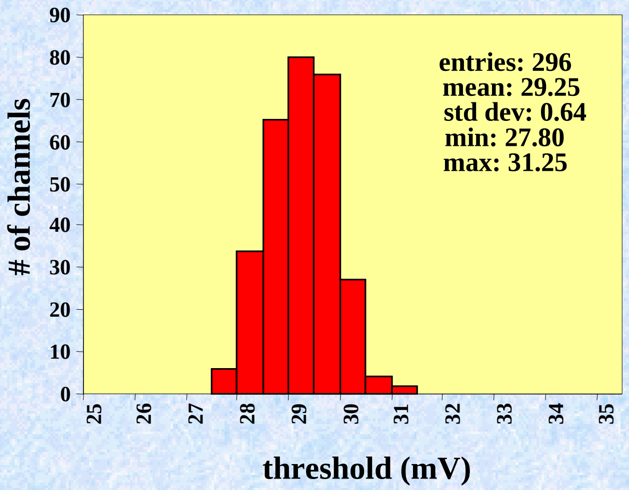
MAD on Board

Threshold uniformity and Noise

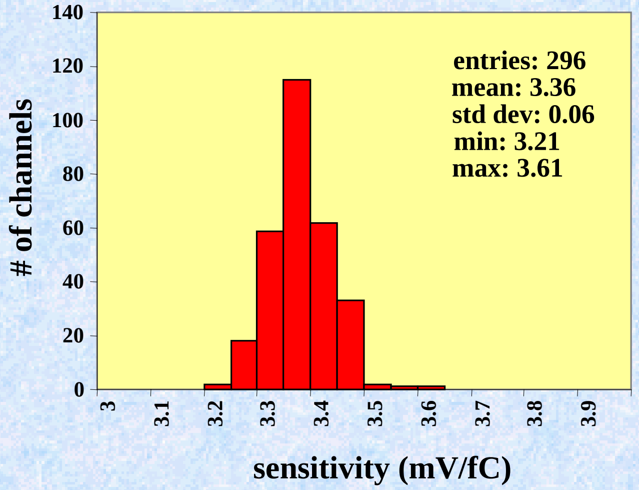
THRESHOLD @ 3 fC INPUT



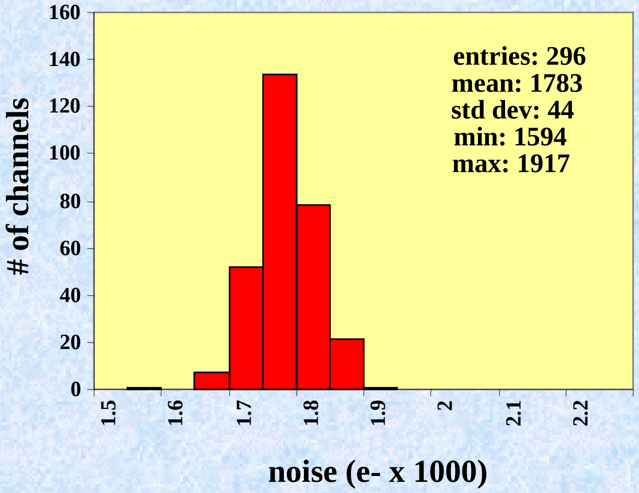
THRESHOLD @ 9 fC INPUT



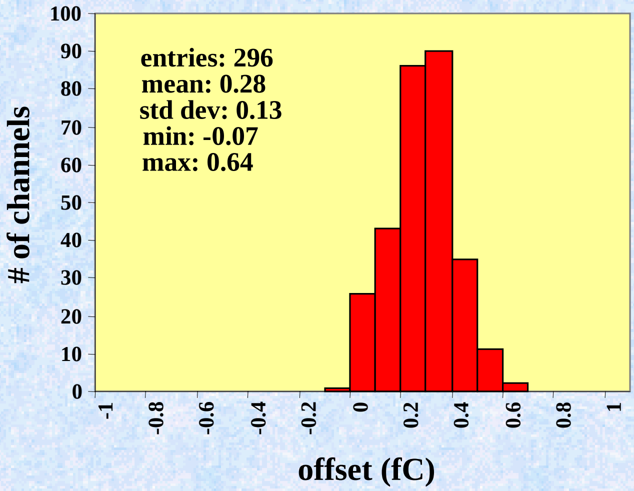
SENSITIVITY



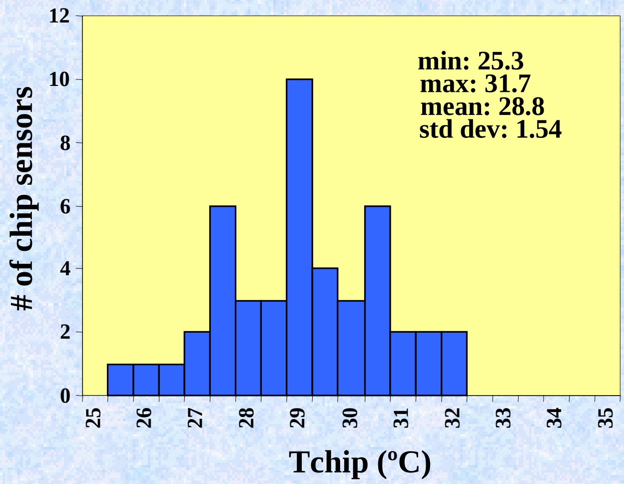
NOISE



OFFSET FROM REGRESSION



TEMPERATURES INSIDE CHAMBER

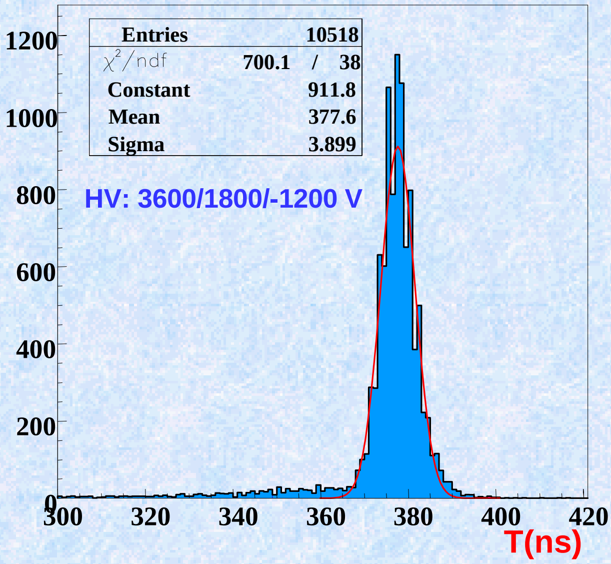


MAD on Beam

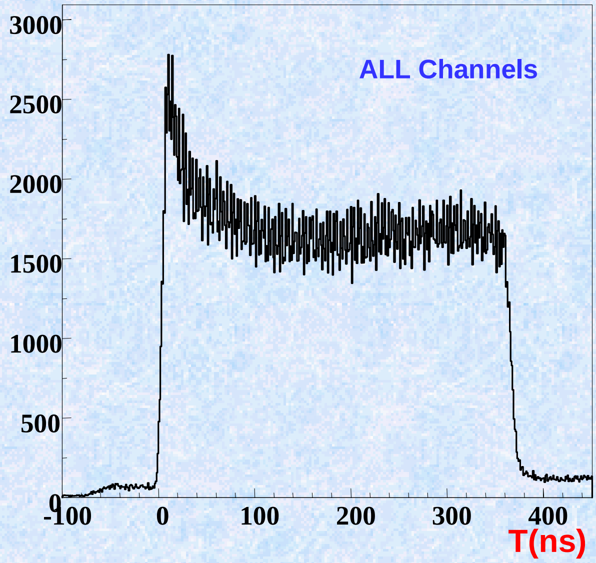
Q4 preliminary results - July '99 test beam

- Q4 prototype with final DT cell design
- chamber full equipped with MAD4 ASICs
- H2 muons test beam at CERN-SpS

Meantimer

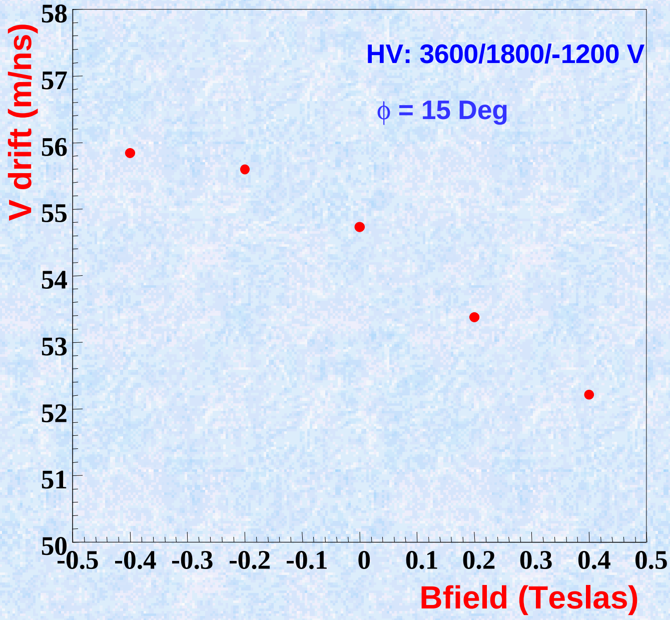


TDC Spectrum

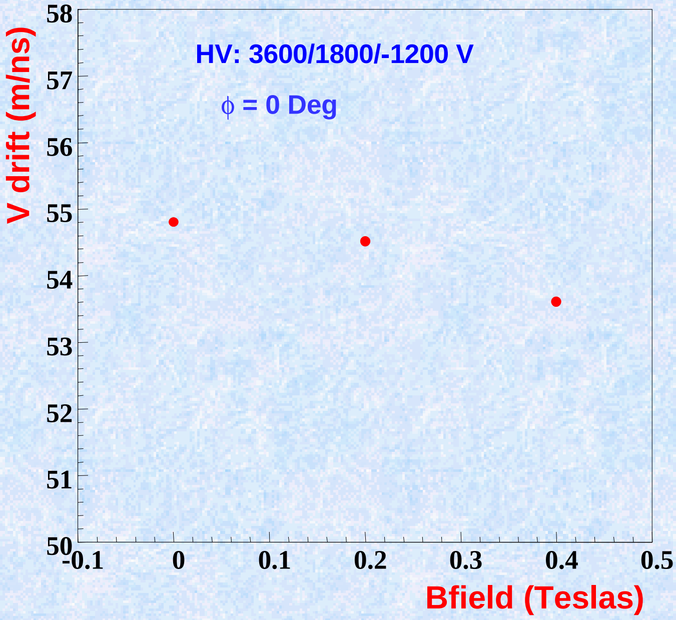


Preliminary results - raw data plots

Drift velocity vs Bfield

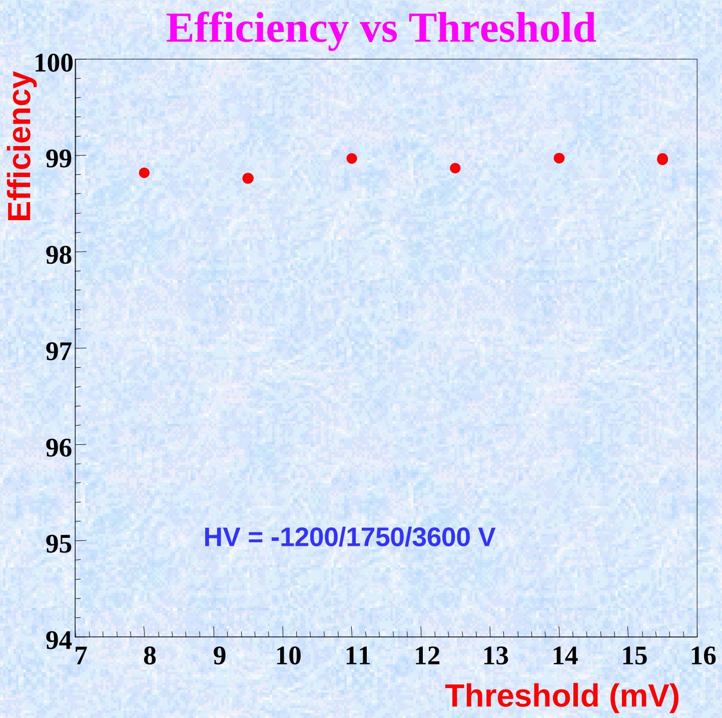


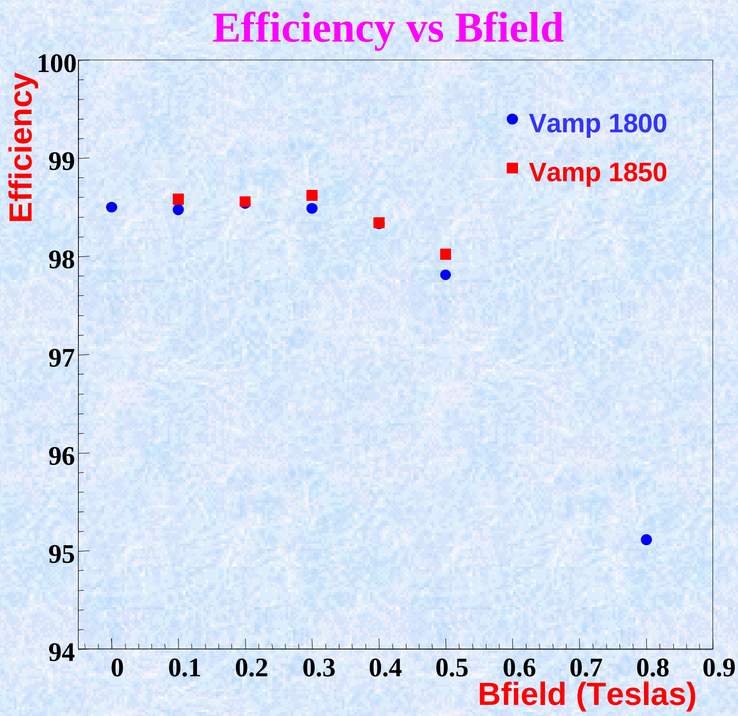
Drift velocity vs Bfield



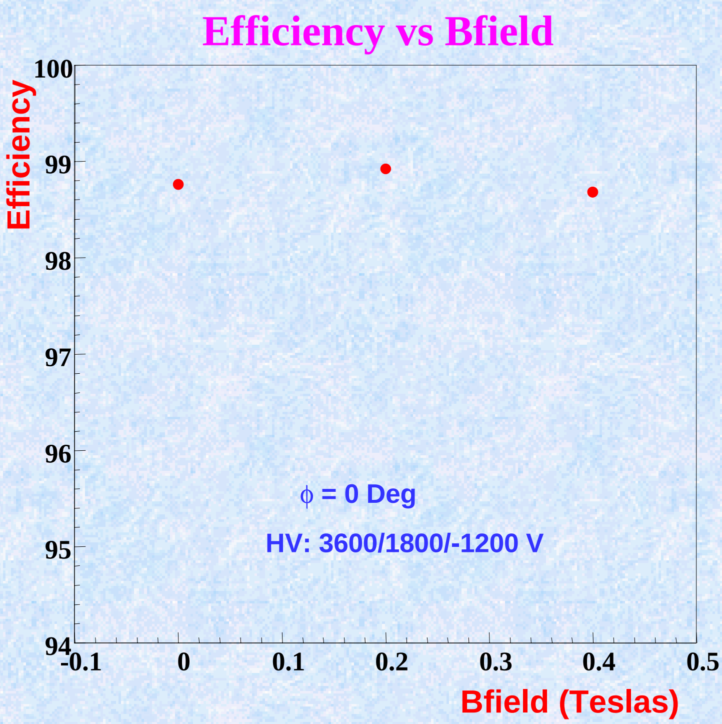
MAD on Beam

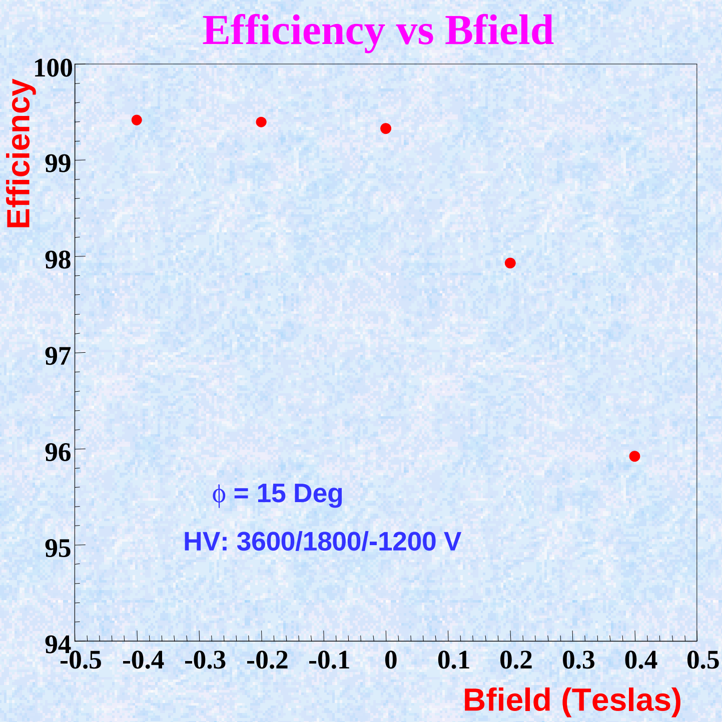
Efficiency vs Threshold and Bfield





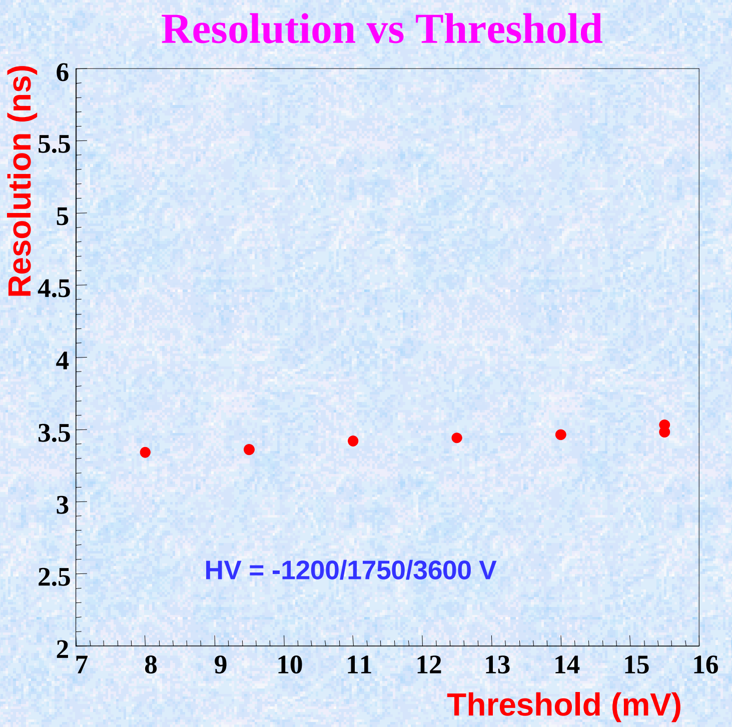
Preliminary results - raw data plots

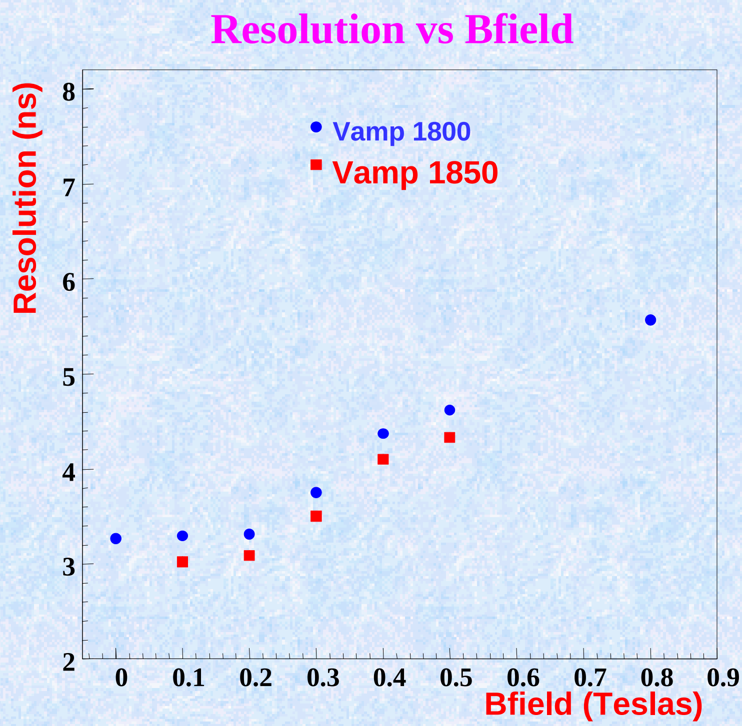




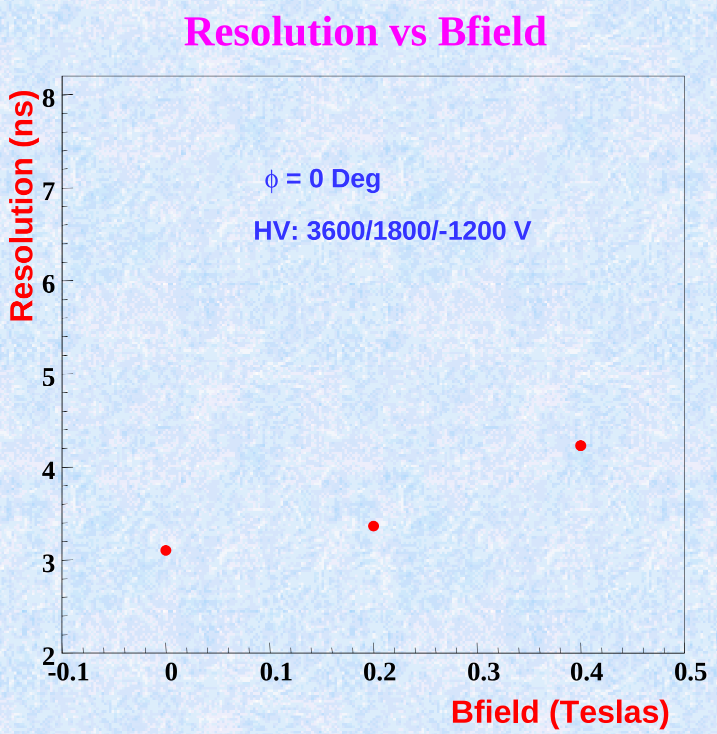
MAD on Beam

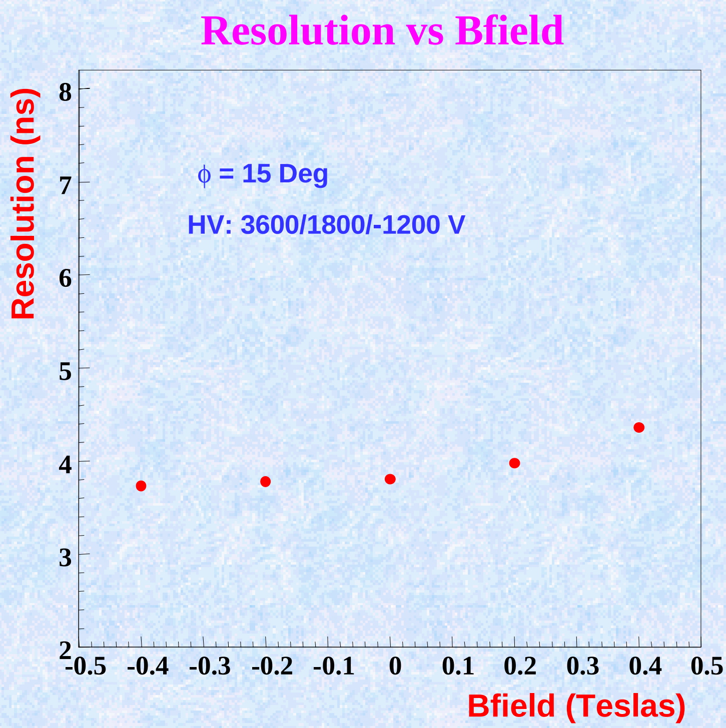
Resolution vs Threshold and Bfield





Preliminary results - raw data plots





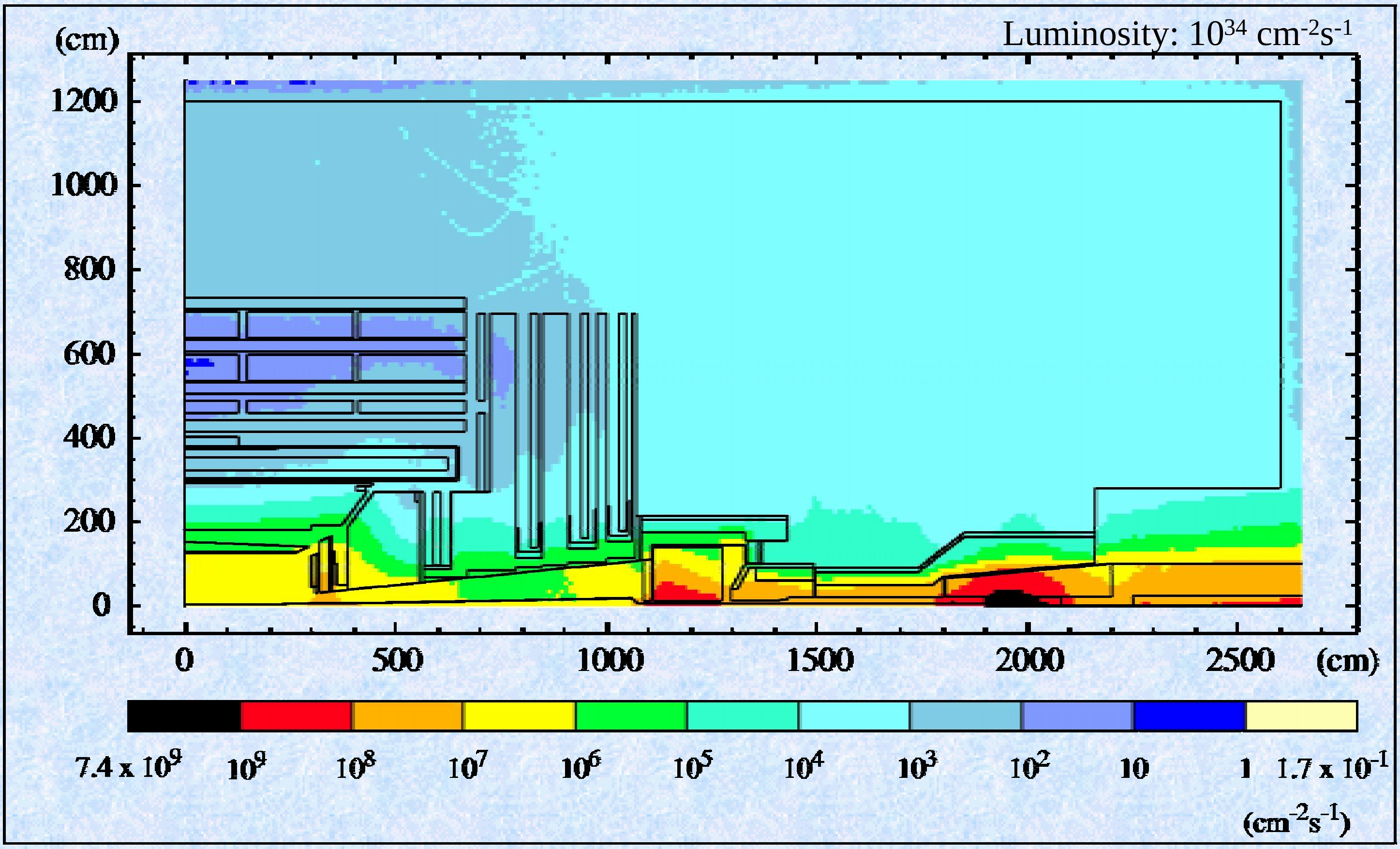
RADIATION TESTS

Gamma and Neutrons Irradiation

neutrons

In CMS barrel irradiation flux is very low,
only neutron flux can give problems by
Single Event Effects:

$5\ 10^{10}$ n/cm^2 for 10y activity (10% thermal)



gamma

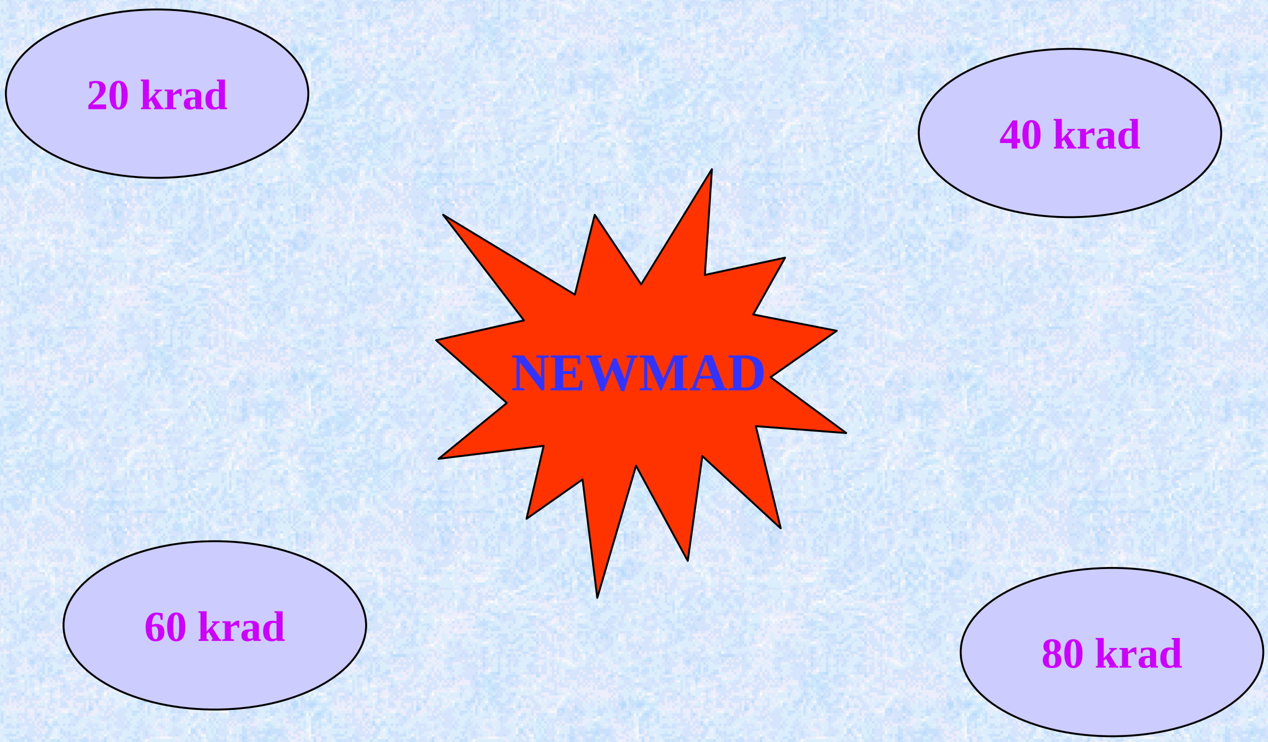
For best ASIC characterisation
gamma irradiation is tested too
(in CMS barrel the expected flux is below 10krad)

RADIATION TESTS

Gamma rays Irradiation

^{60}Co source

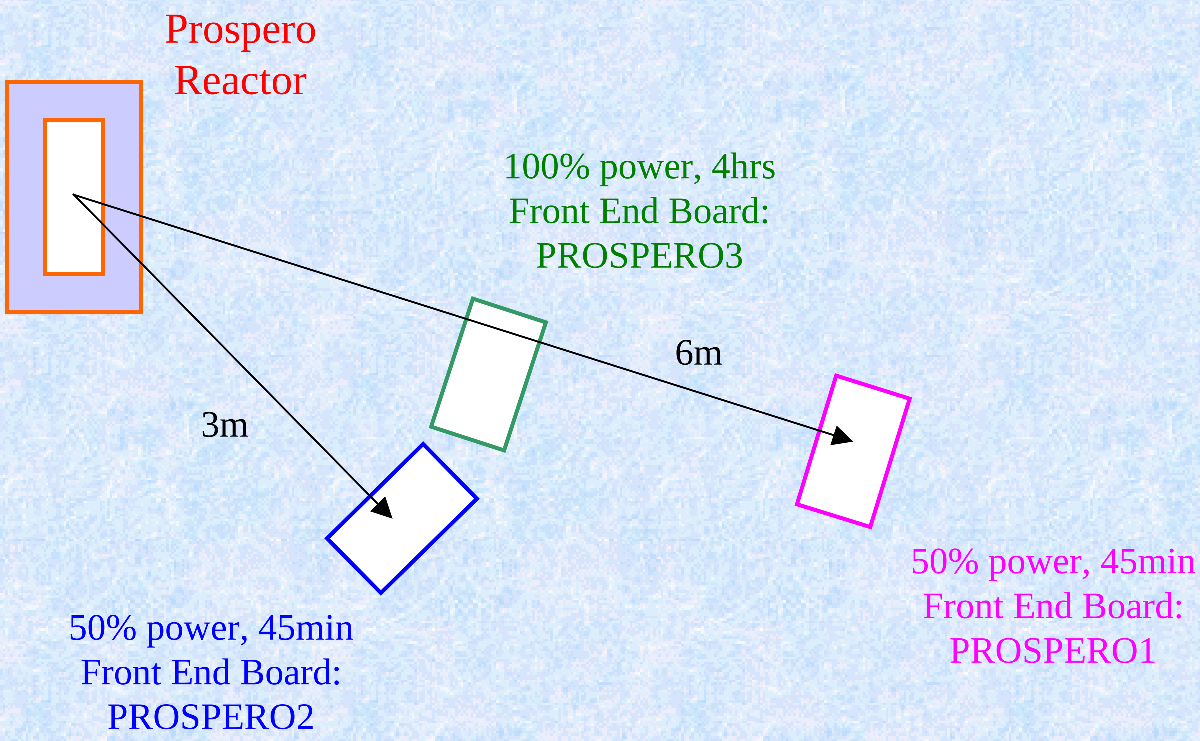
4 NEWMAD prototypes exposed to gamma rays at Bologna



NO dynamic or static changes measured!

RADIATION TESTS

Fast Neutrons at PROSPERO Facility

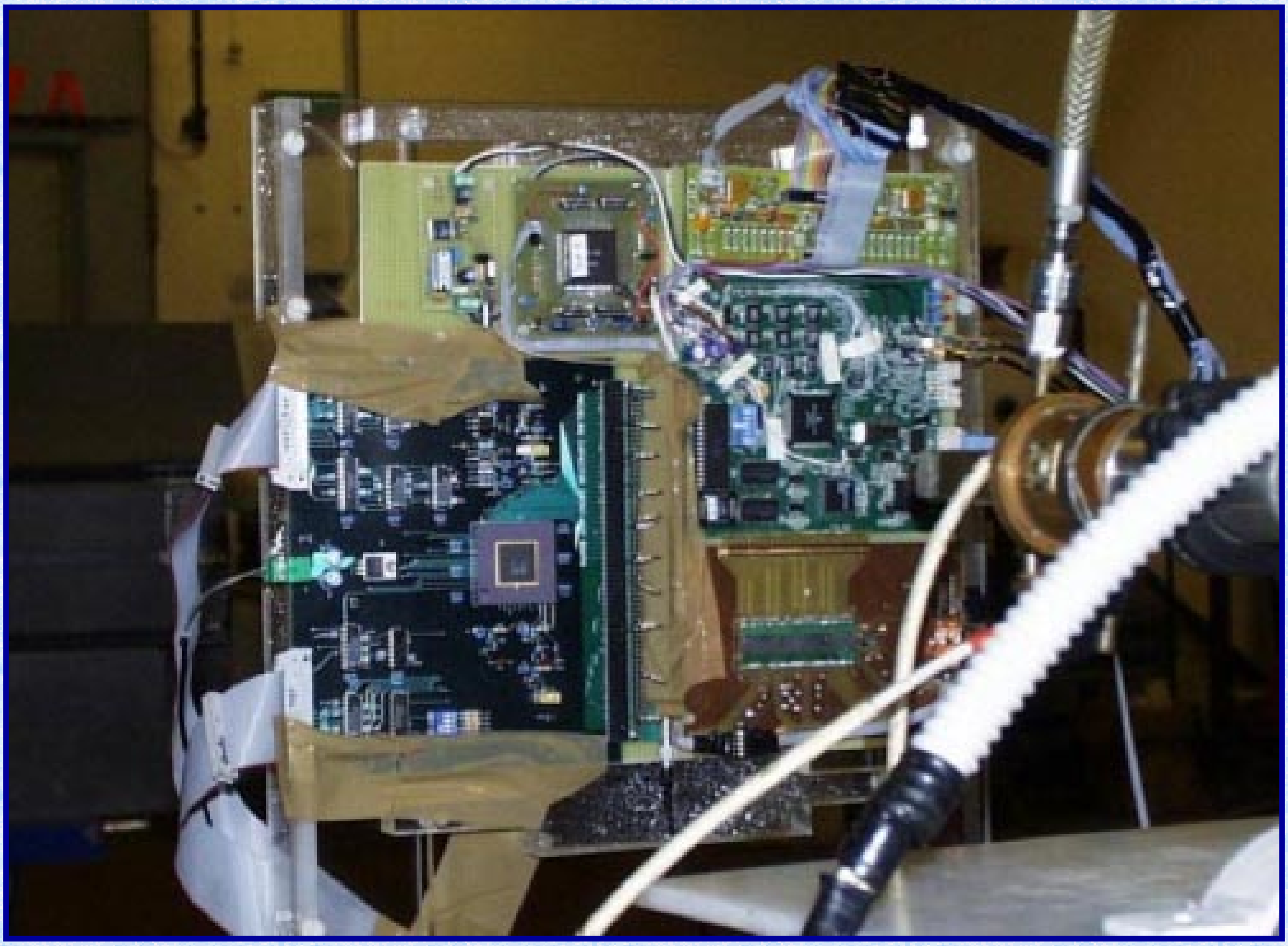


FRONT END BOARD	REACTOR DISTANCE	n/cm^2 EQ. 1MeV(SI)
PROSPERO1	6m	**$4.85\ 10^{10}$**
PROSPERO2	3m	**$1.53\ 10^{11}$**
PROSPERO3	3m	**$1.72\ 10^{12}$**

NO dynamic or static changes measured!

RADIATION TESTS

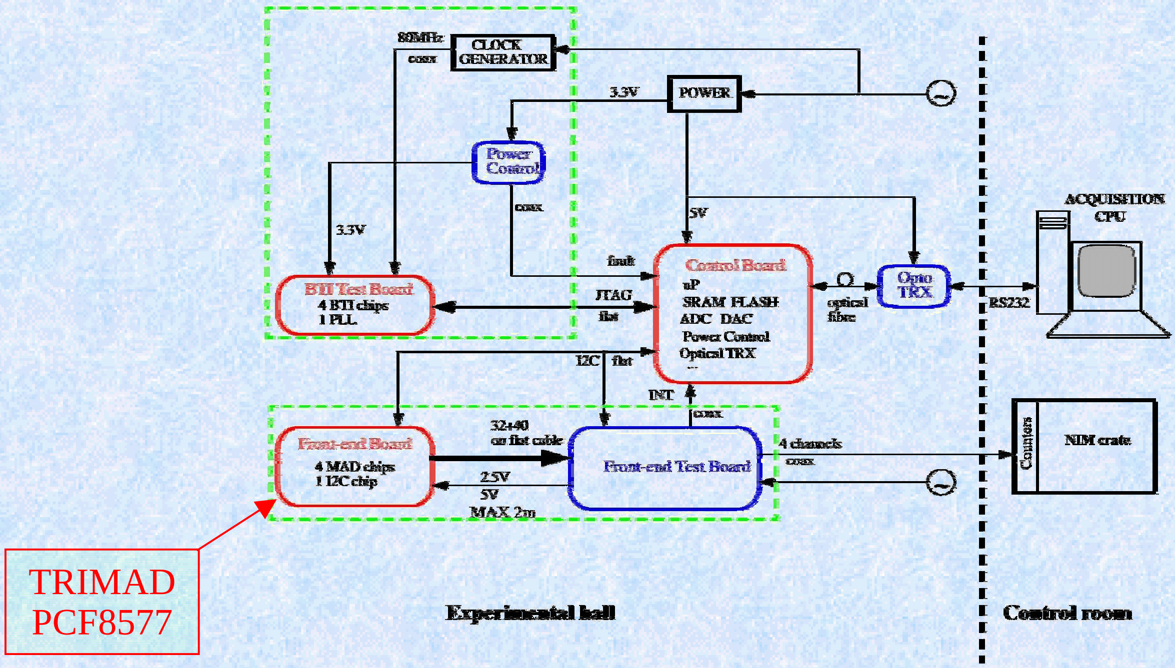
SE induced by Fast and Slow Neutrons at LNL



Test Setup

RADIATION TESTS

SE induced by Fast and Slow Neutrons at LNL



CN Van de Graaff: 7 MeV Deuterium beam

Thermal Neutrons

⇨ Graphite moderator — $9.1\ 10^{9}$ n/cm^2

Fast Neutrons (up to 10 MeV)

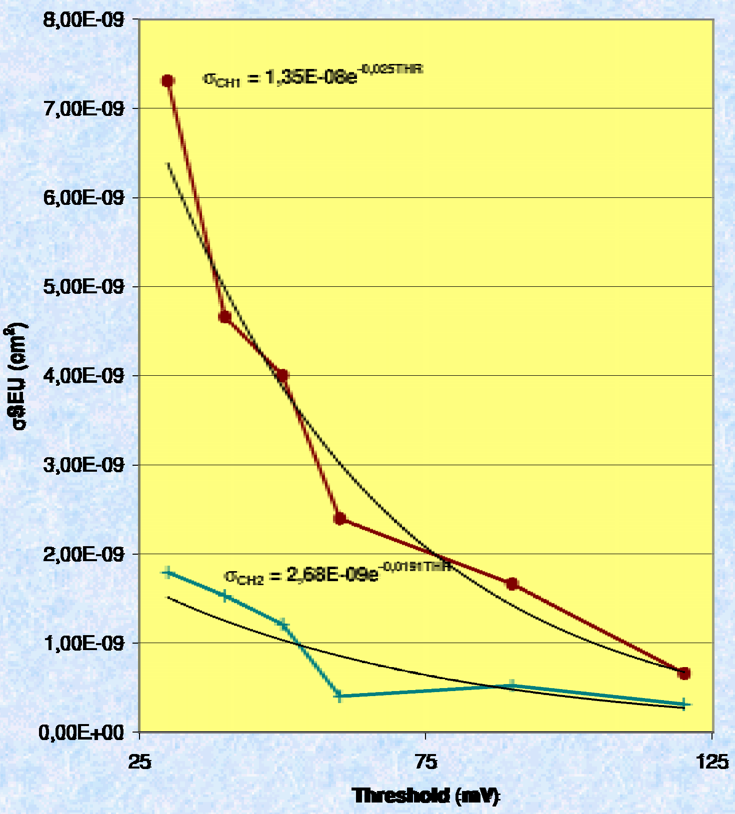
⇨ $^{9}Be(d,n)^{10}B$ reaction — $4.0/6.3\ 10^{10}$ n/cm^2

NO changes measured on MAD and I^2C ICs!

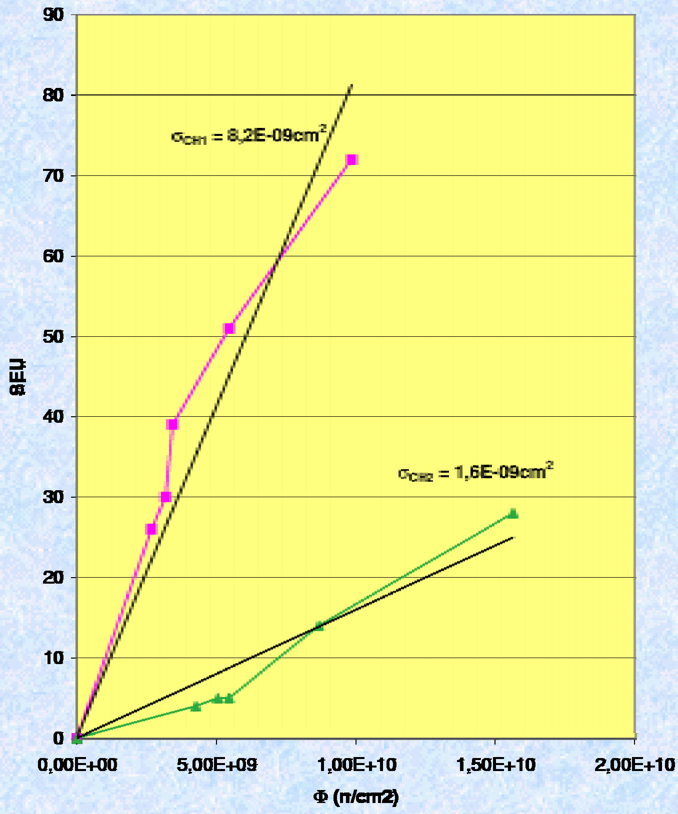
RADIATION TESTS

SE induced by Fast and Slow Neutrons at LNL

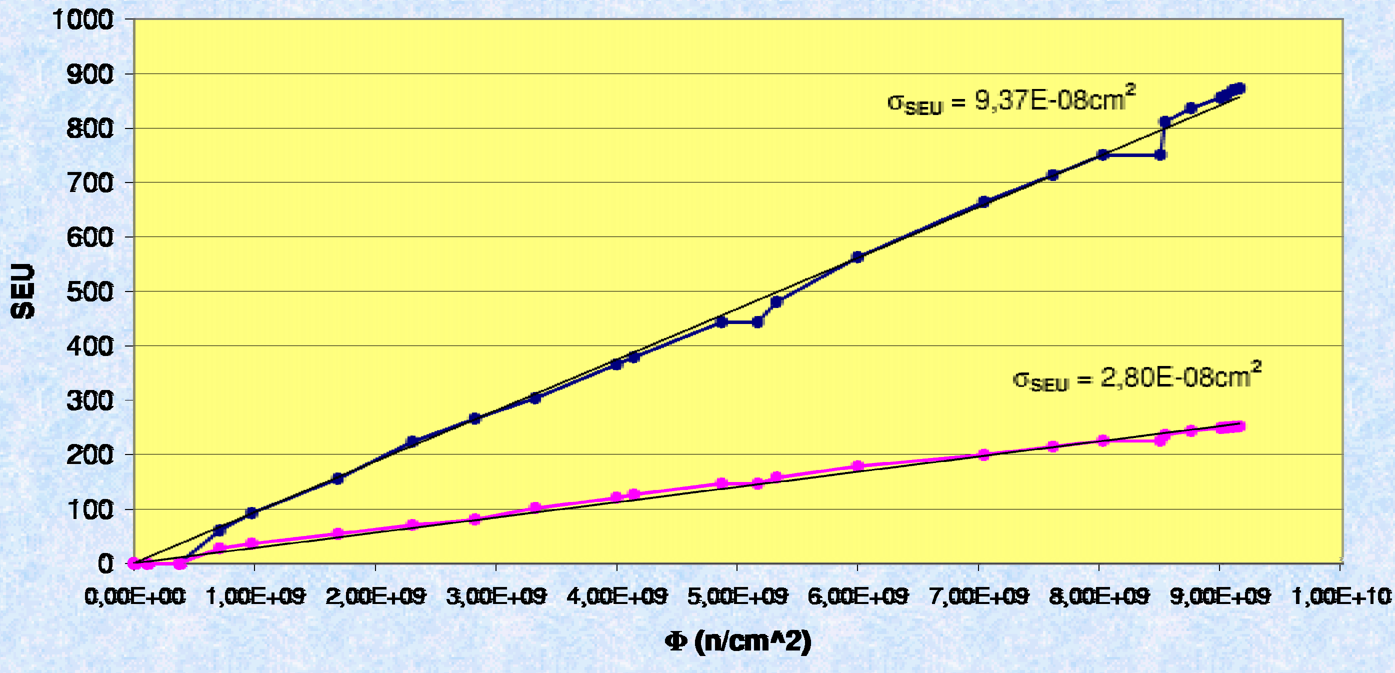
MAD SEU cross-section versus threshold



Fast Neutrons induced SEU on MAD @ thr=30mV

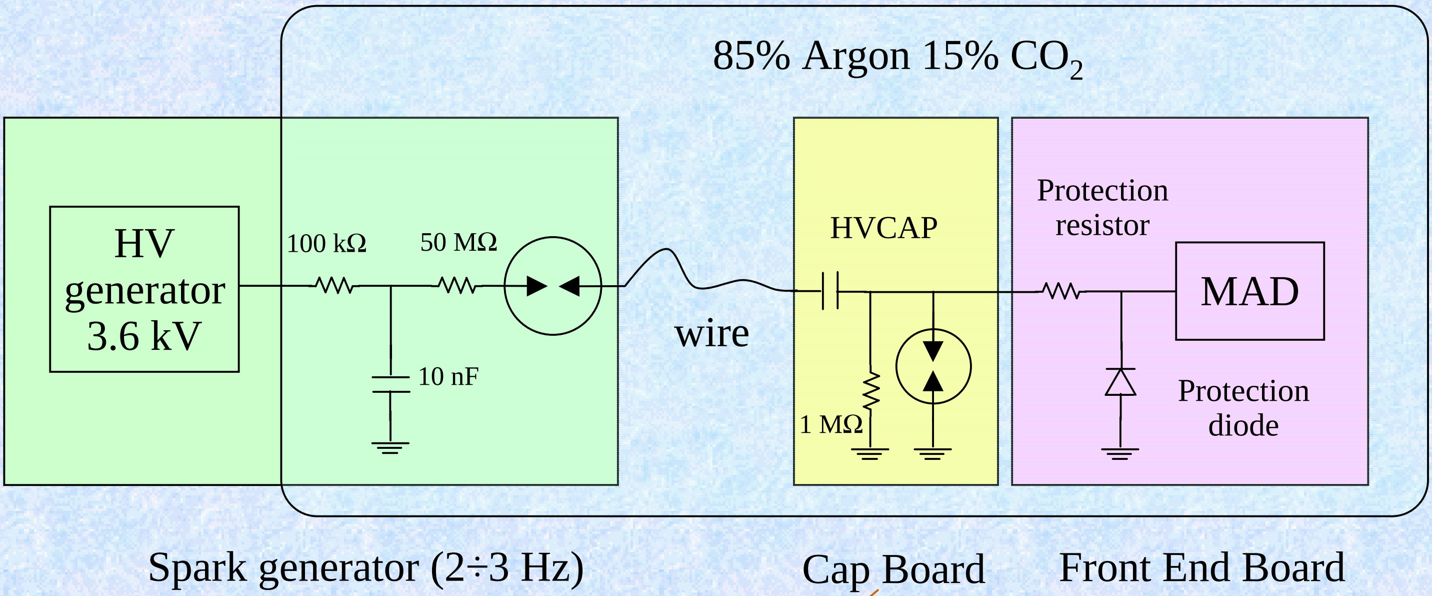


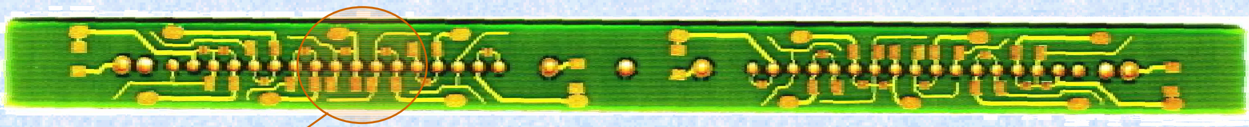
Thermal neutrons induced SEU on MAD @ thr=60mV



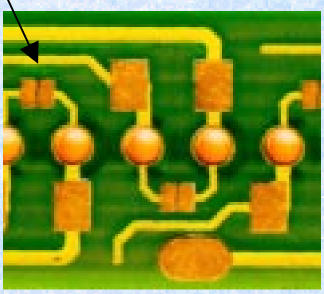
DISCHARGES TESTS

Drift Tubes discharges simulation





Spark Gap

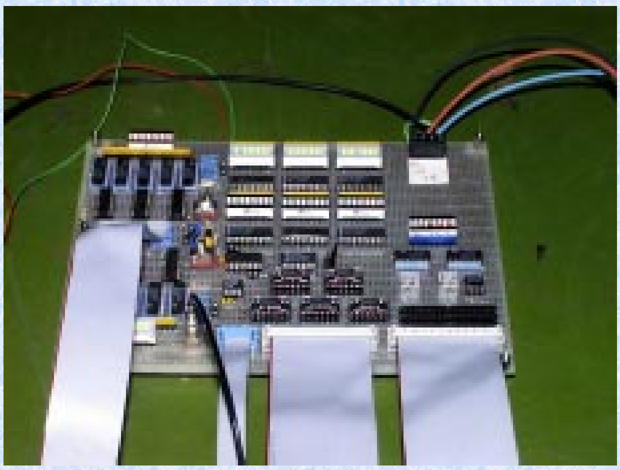


- Tests performed in gas $ArCO_2$ (85:15)
- protection resistor of 39 Ω
- BAS678 protection diode
- HVCAP of 470 pF

- 100 µm spark gap on Cap Board for increasing protection (spark @ about 500 V)
- more than 10 A of peak current during spark (estimated)
- circuit withstood more than 100k sparks
  (hope for not such an environment during operation)

AGEING TESTS

Test Setup



Test performed at 125 °C
in N_2 environment
for about 2000 hours

AGEING TESTS

The failure rate λ is measured as the number of failures occurring per time expressed in number of failures per 10^9 device-hours;
its inverse, the MTTF, is the mean time to have a device failure:

$$MTTF = \frac{1}{\lambda}$$

Failure rate estimation is performed with chi-square distribution to get a reasonable approach for reliability tests which ends in zero units having failure:

$$\lambda = \frac{\chi^2\left[UCL;2\cdot(r+1)\right]}{2\cdot n\cdot t\cdot b}$$

UCL = Upper Confidence Limit (60%)
r = number of reliability rejects
$n\cdot t$ = number of device hours
b = acceleration factor

Means that with a probability of 60% the actual failure rate will not be higher then the estimated value

Low failures rate ➡ accelerated tests at high T

The acceleration factor is expressed by Arrhenius equation:

$$b = e^{\left[\frac{A_e}{k}\left(\frac{1}{Top}-\frac{1}{T_{test}}\right)\right]}$$

B = acceleration factor
A_e = activation energy (0.7eV)
k = Boltzman's costant
T_{op} = desired operation T
T_{test} = test T

T_{op} (°C)	T_{test} (°C)	b	MTBF (year)	Failure/10LHCy
15	125	2402	1.21E+08	36
20	125	1485	7.51E+07	58
25	125	933	4.72E+07	93
30	125	596	3.01E+07	145
55	125	77	3.91E+06	1107

50000 devices

STATUS - CONCLUSION

Very good performances at low power.
Also yield seems good.

ASIC includes fast and slow masking feature and Temperature sensor.

Gamma and neutrons irradiation tests passed without device failure.

Estensively & successfully tested with muon beam.
CMS requests fulfilled.

The MAD

Further work need to be carried out on following items:

- **tests on prototypes and preserie**
- **design final version of Front End Board**
- **definition of tests for mass production of Front End System.**