# The MAD

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

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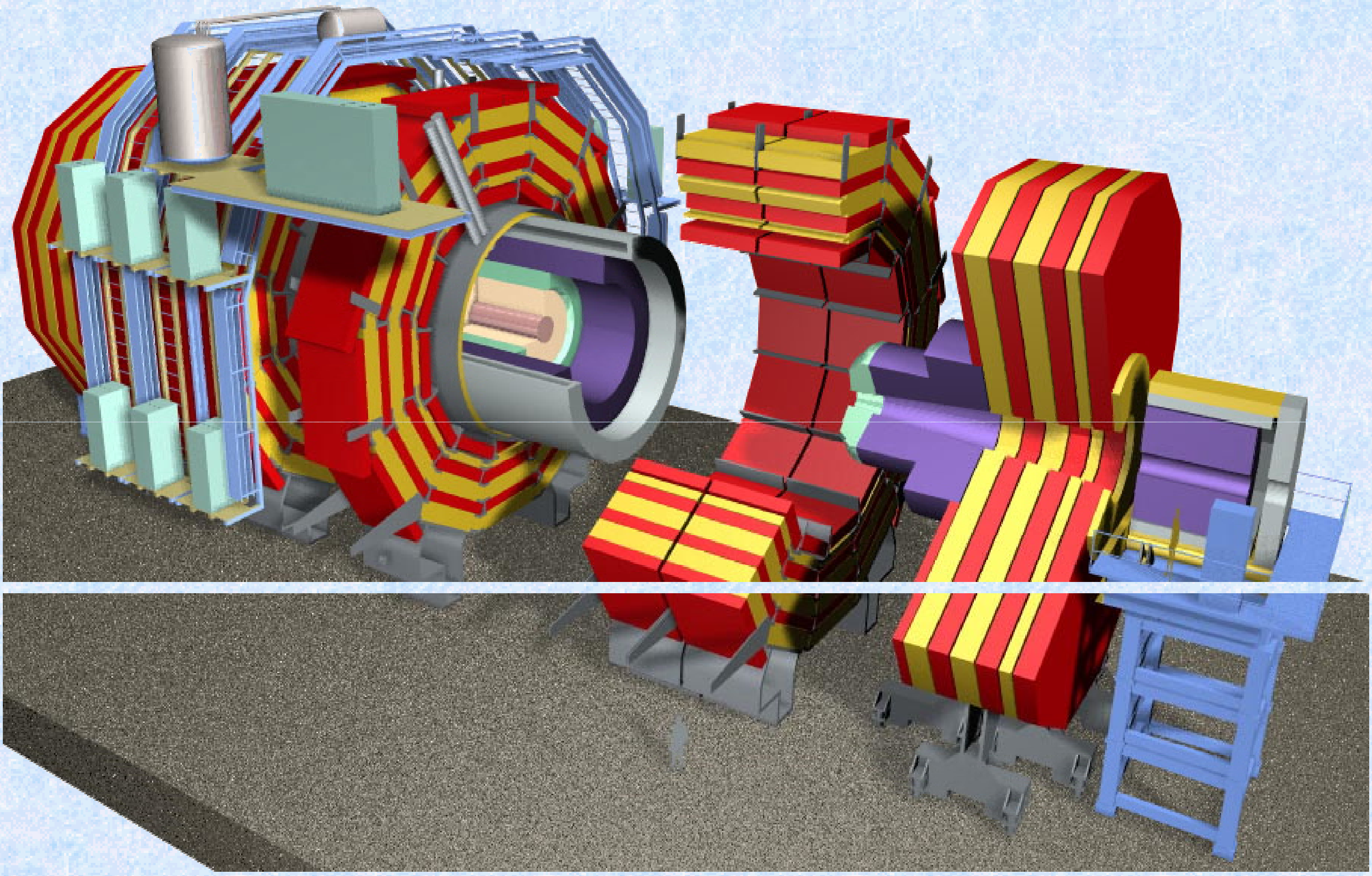
# Compact Muon Solenoid

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

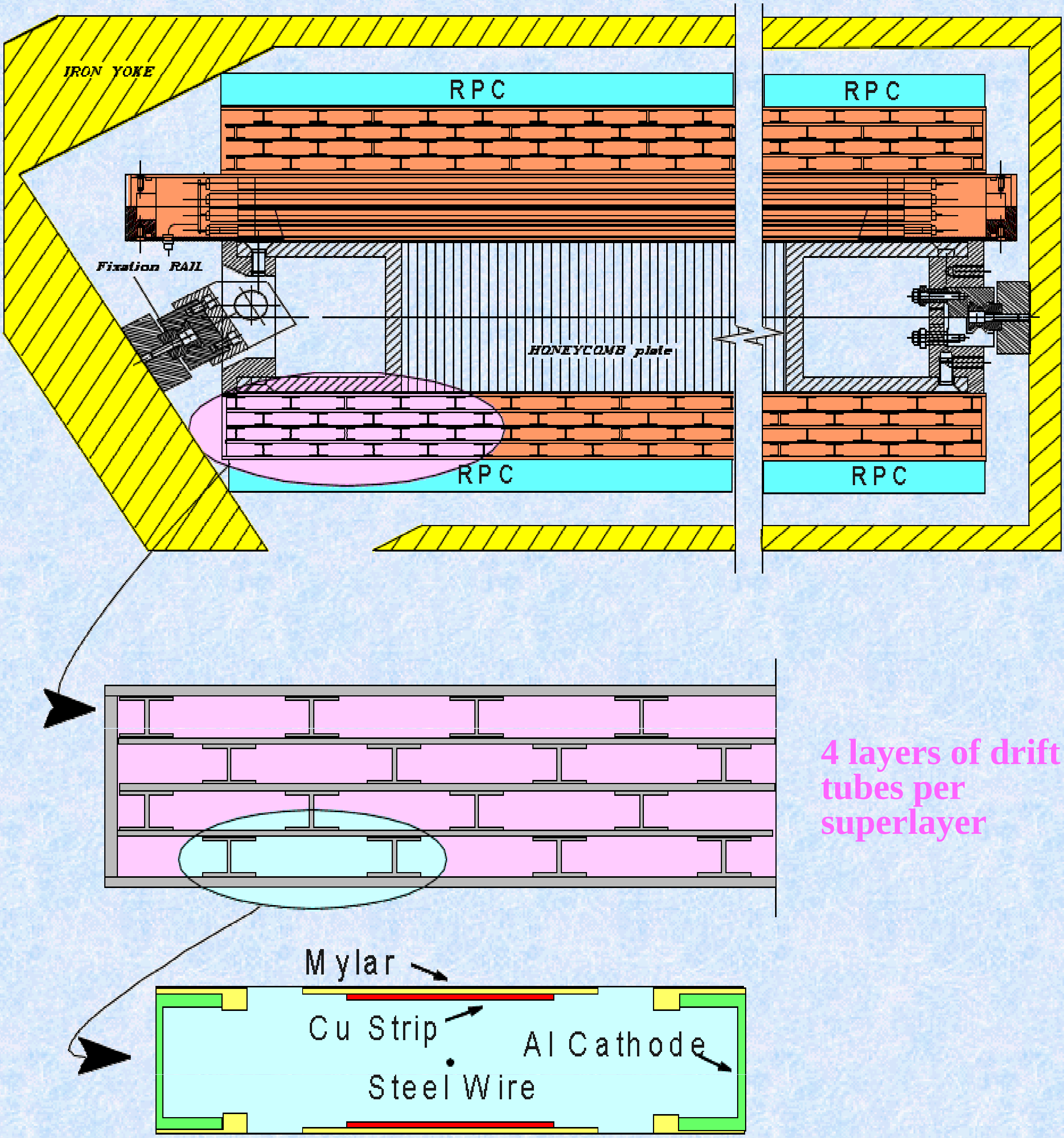


**The main design goals of CMS are:**

**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**

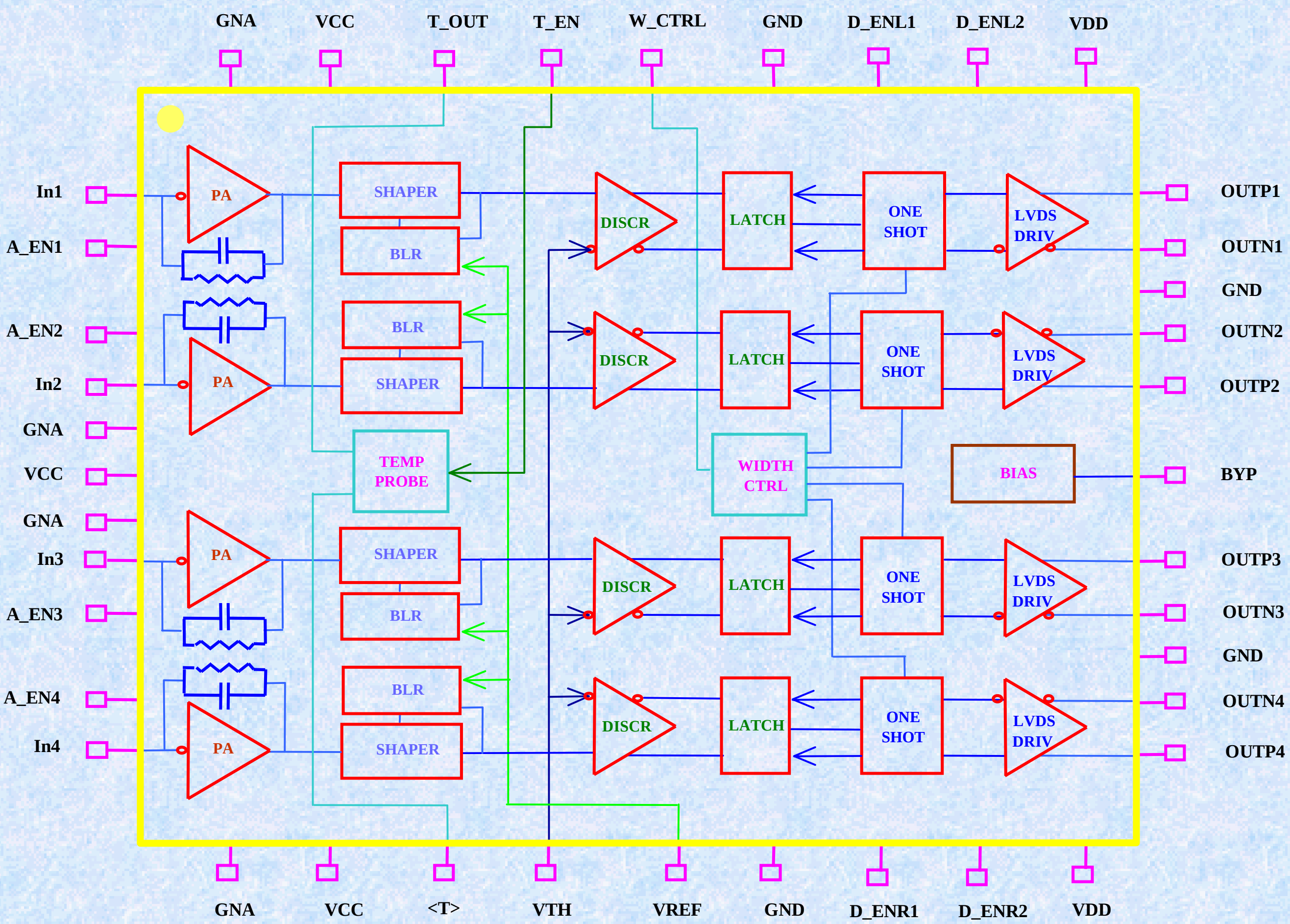
**3 complete electronic chains to test preamplifier and masking**
**0.8u BiCMOS Tech.**

**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<br>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<br>Low: 1.2-1.3 V |
| W_CTRL | Output width control, common to all channels | Usually resistor to ground |
| OUTN(1-4)<br>OUTP(1-4) | Differential output channel 1-4, LVDS compatible levels | 120 Ohm terminating resistor |

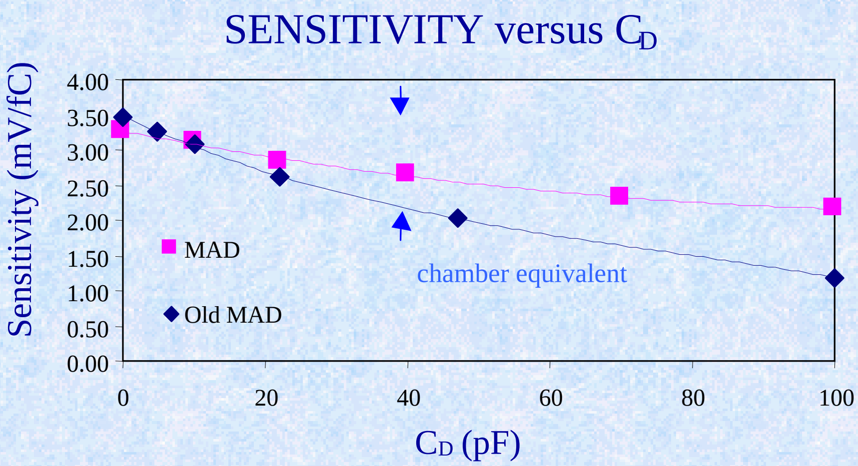
# MAD Front End Chip

## 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/ ºK sensitivity, 3 ºK max error @ 25 ºC
- **fast and slow masking features** for chamber test and to disable noisy channels

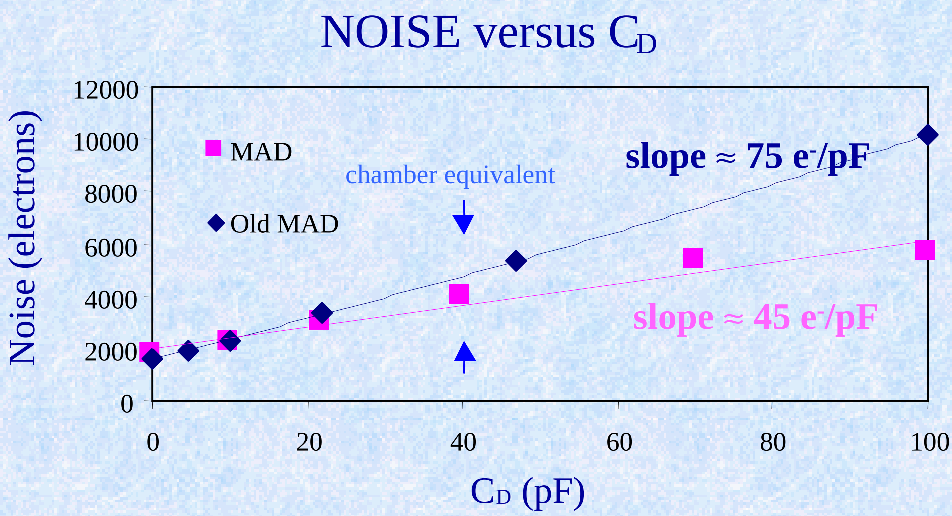
# MAD Front End Chip

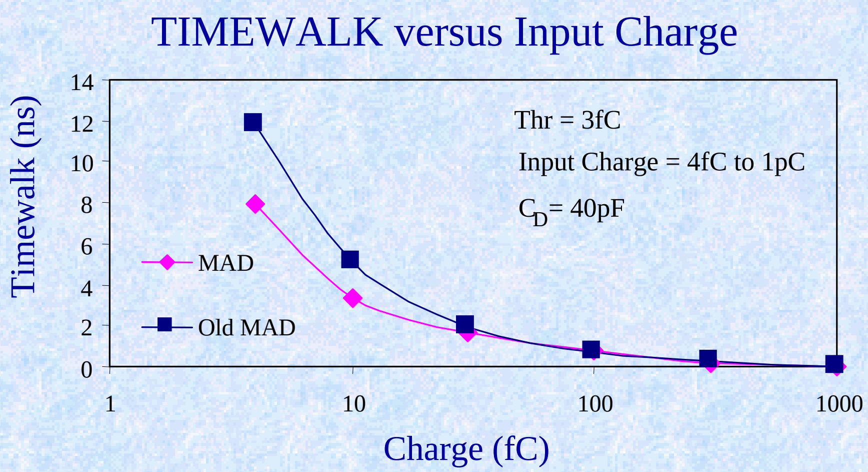
## Sensitivity, Noise and Timewalk




Last version is compared with old one

Performances versus $C_D$ are all improved



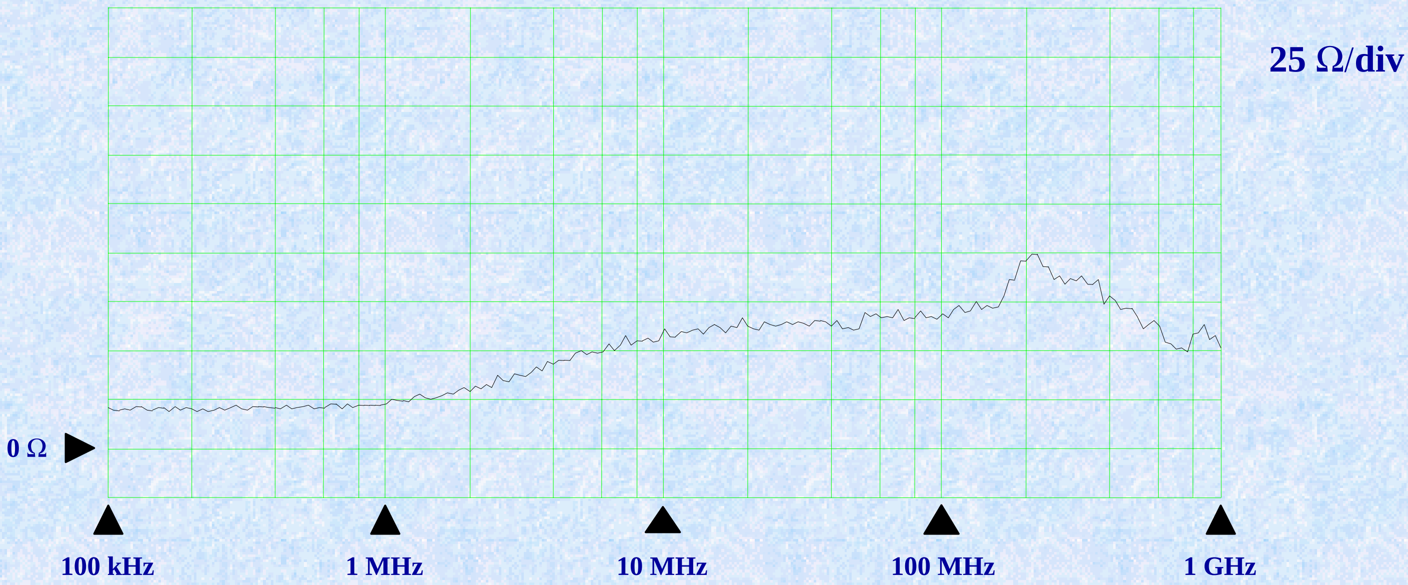

New version include full masking feature

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

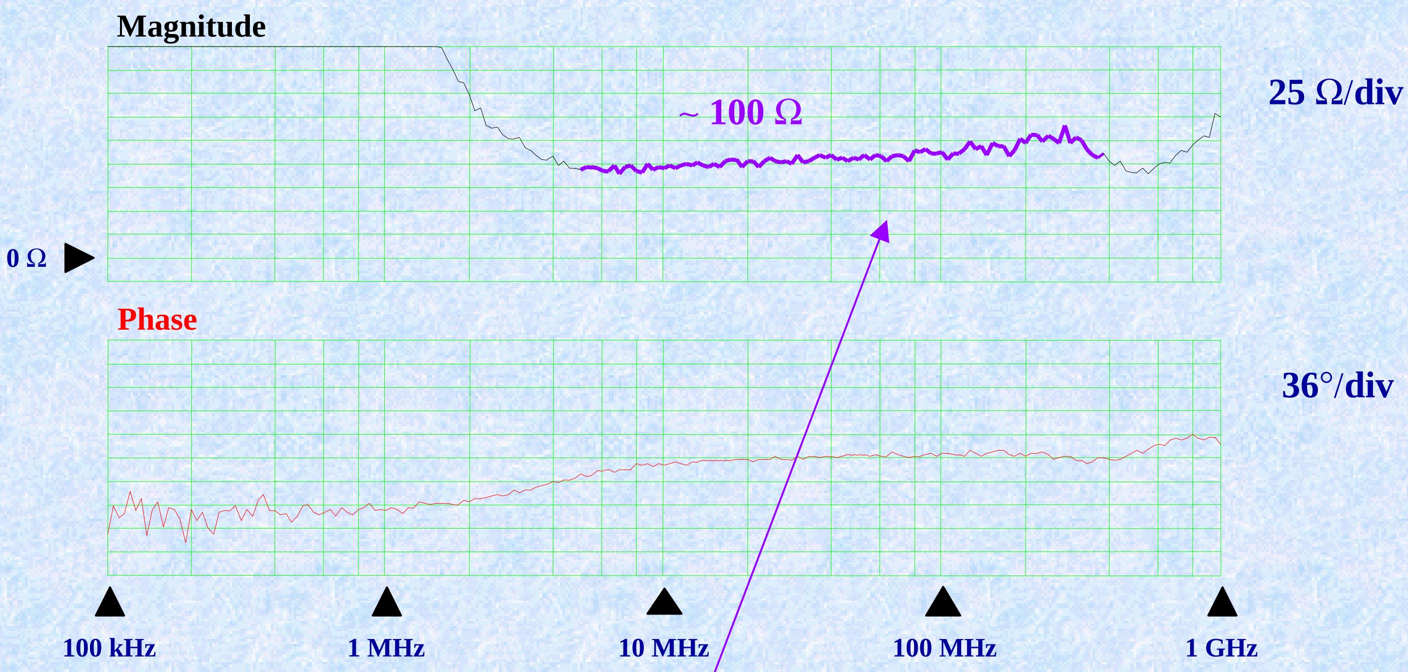
# MAD Front End Chip

## Input Impedance

Impedance with input pin disconnected from PCB



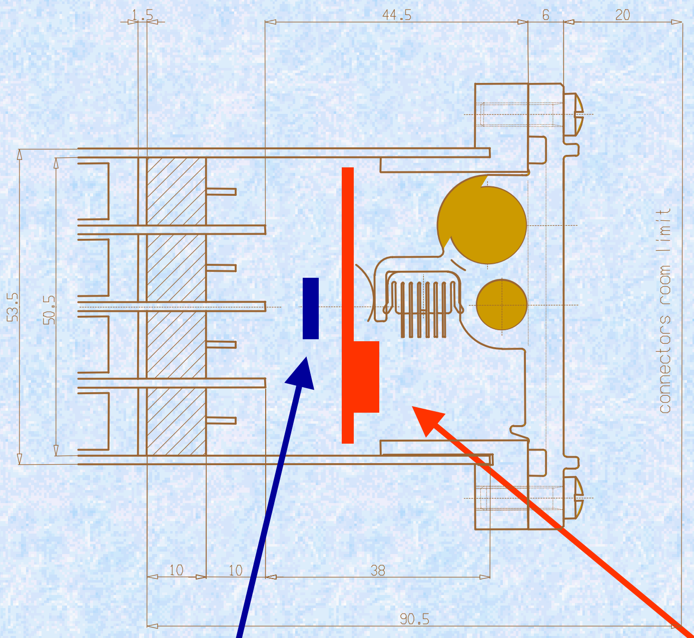

Impedance with series protection resistor (39 Ω) and HVCAP




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

# MAD Front End Board
## (for MAD4 prototype)

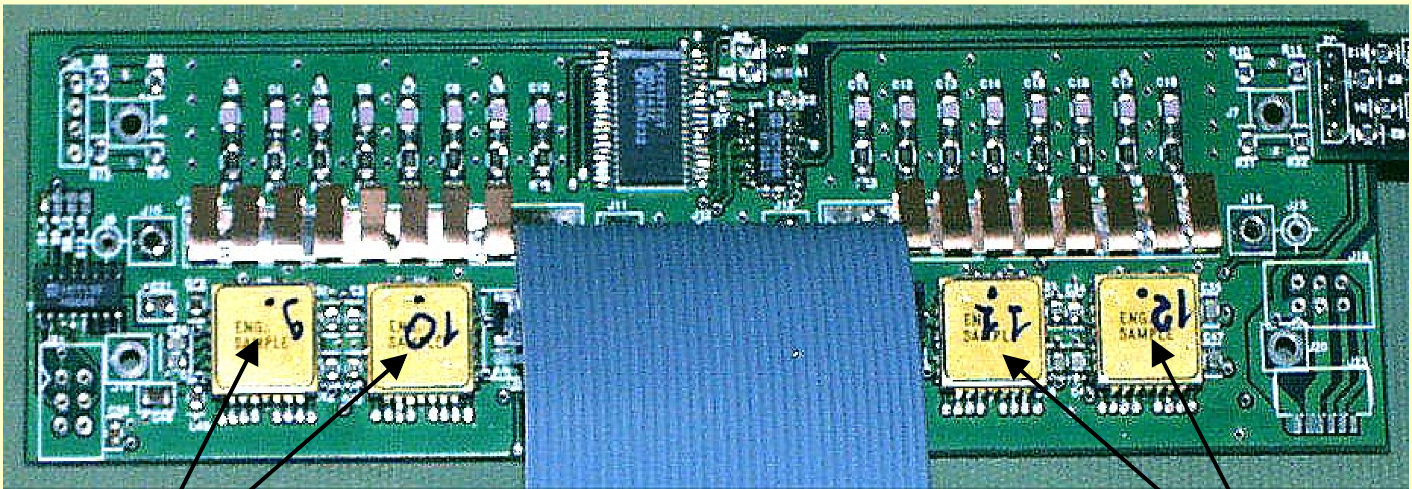
**Chamber cross section**




Cap Board

Front End Board

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



MAD

MAD

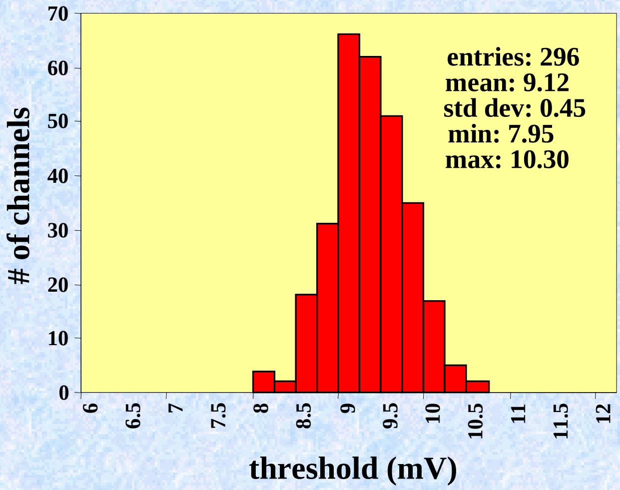
## CHARACTERISTICS

- **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)**

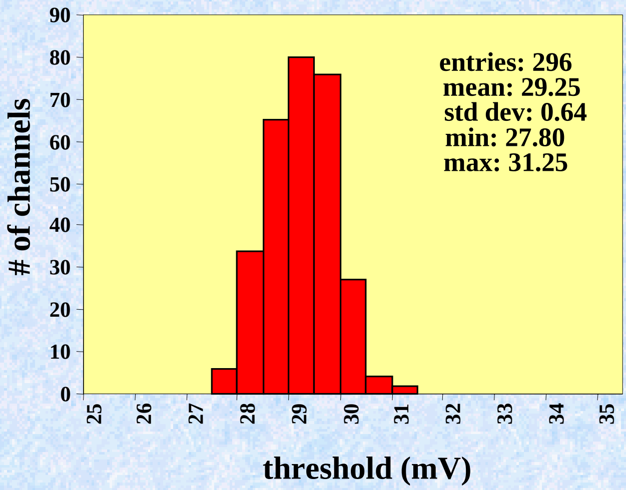
# MAD on Board

## Threshold uniformity and Noise

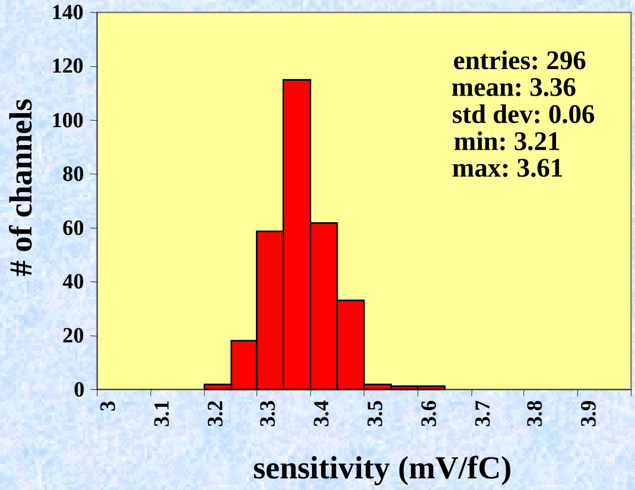
### THRESHOLD @ 3 fC INPUT



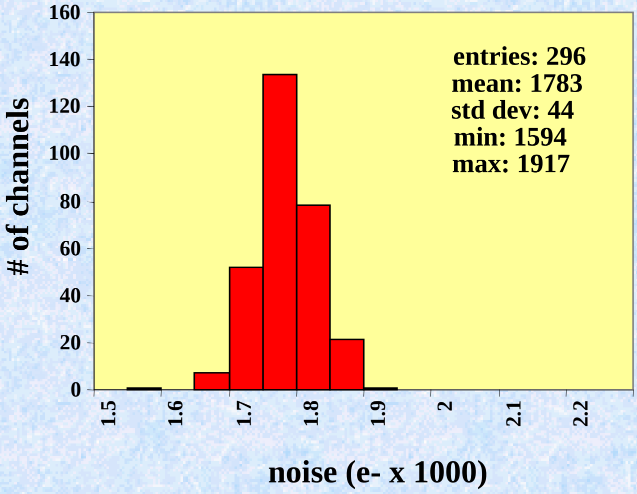

### THRESHOLD @ 9 fC INPUT



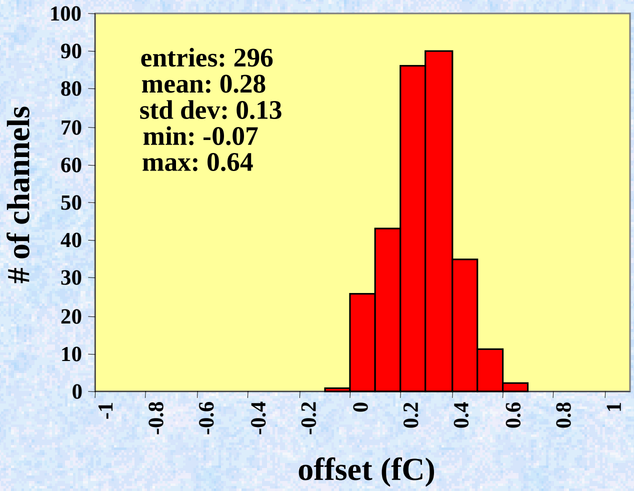

### SENSITIVITY



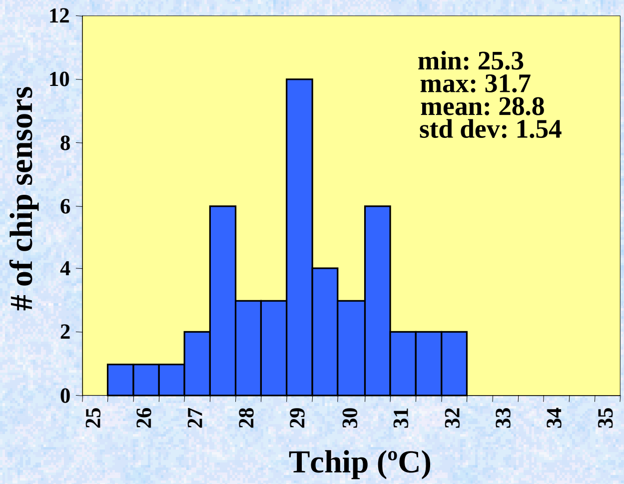

### NOISE




### OFFSET FROM REGRESSION




### TEMPERATURES INSIDE CHAMBER

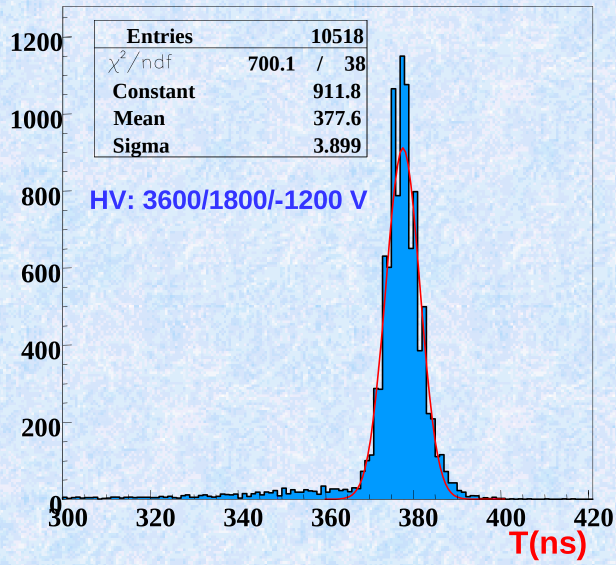


# MAD on Beam

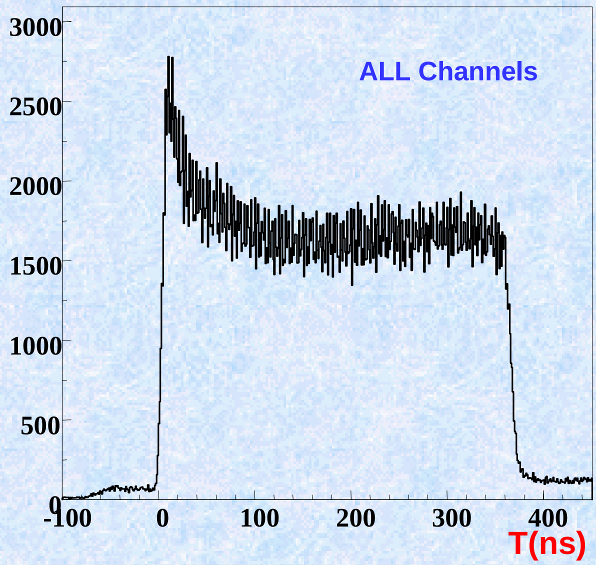
## Q4 preliminary results - July '99 test beam

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

### Meantimer

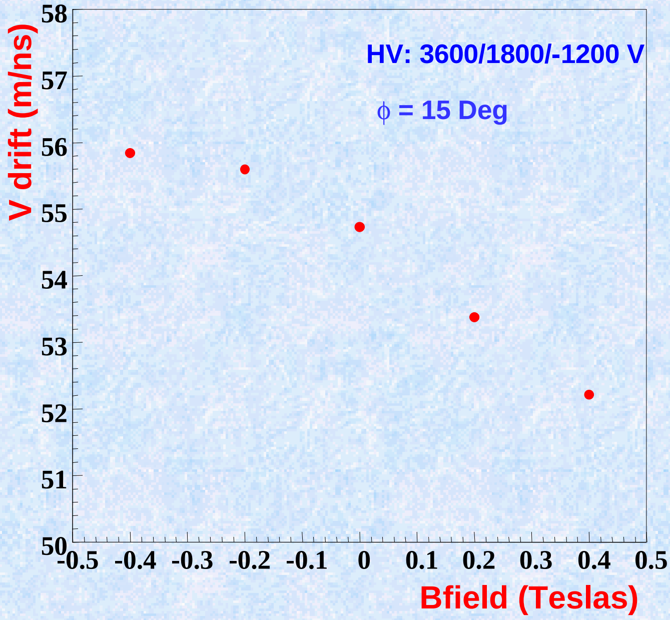



### TDC Spectrum




Preliminary results - raw data plots

### Drift velocity vs Bfield

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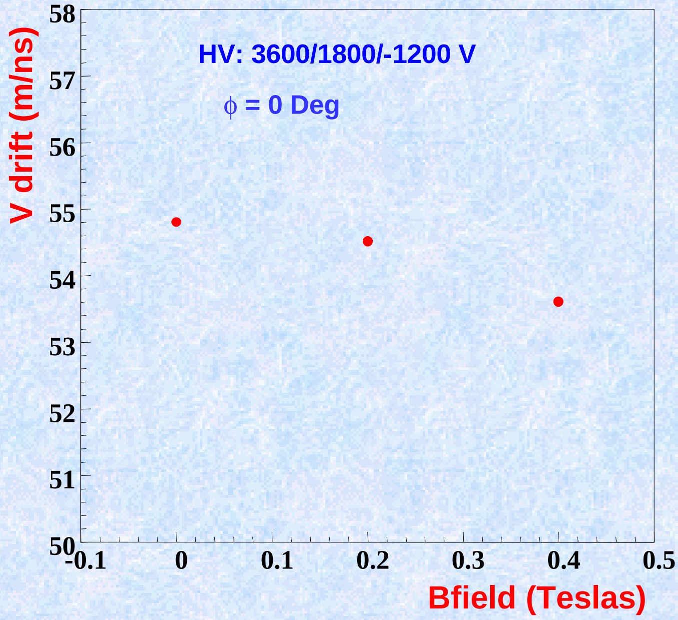
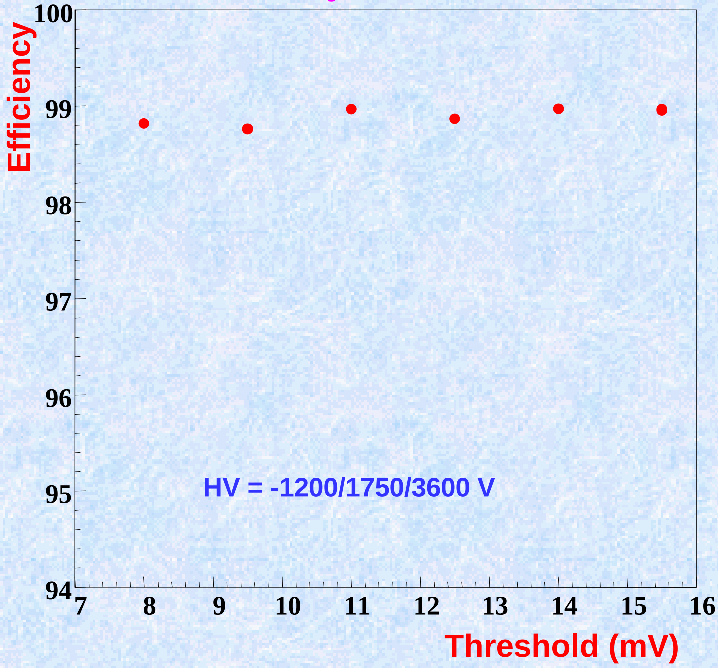


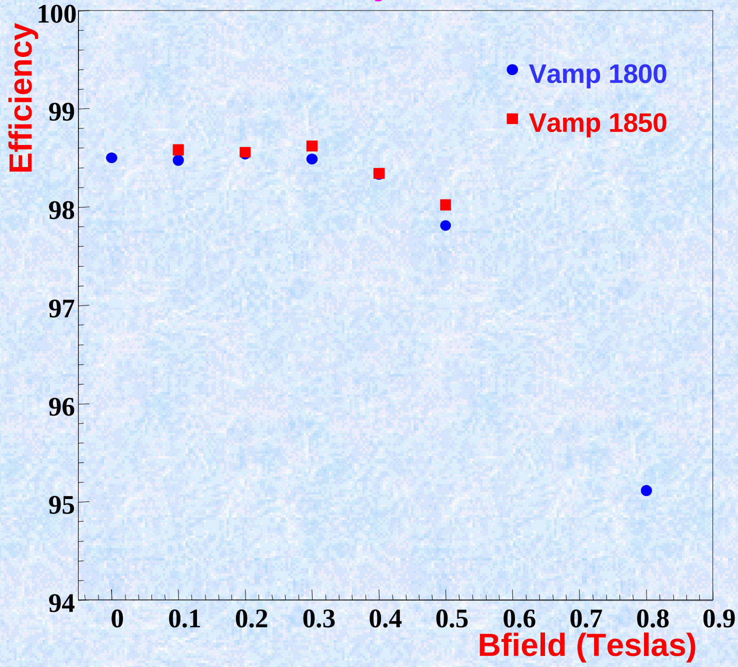
# MAD on Beam

## Efficiency vs Threshold and Bfield

### Efficiency vs Threshold

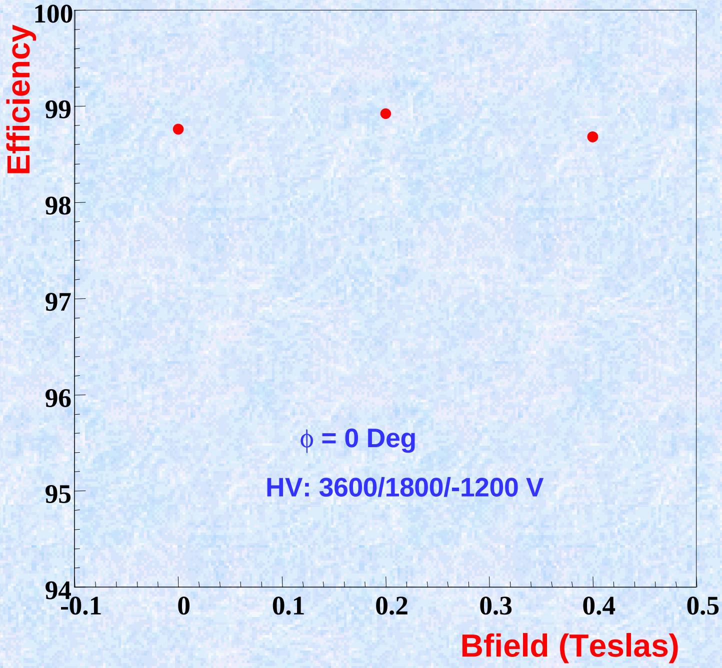



### Efficiency vs Bfield

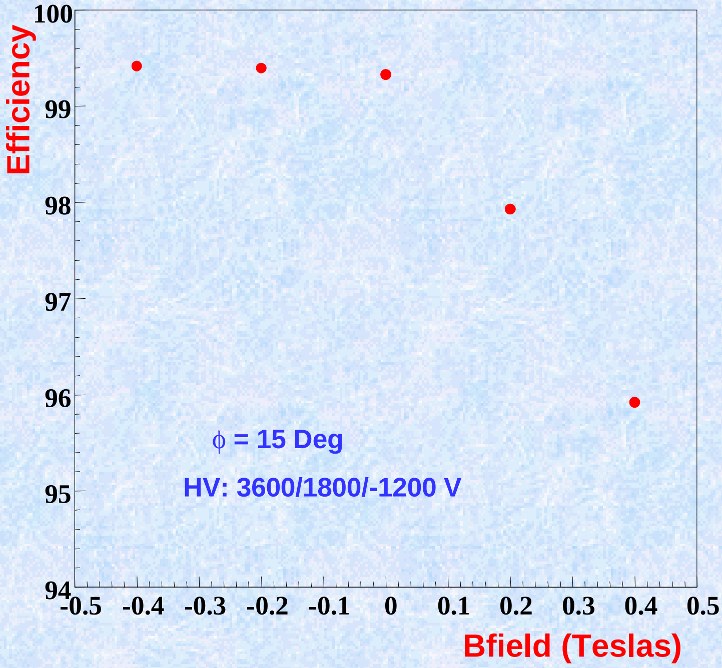



Preliminary results - raw data plots

### Efficiency vs Bfield

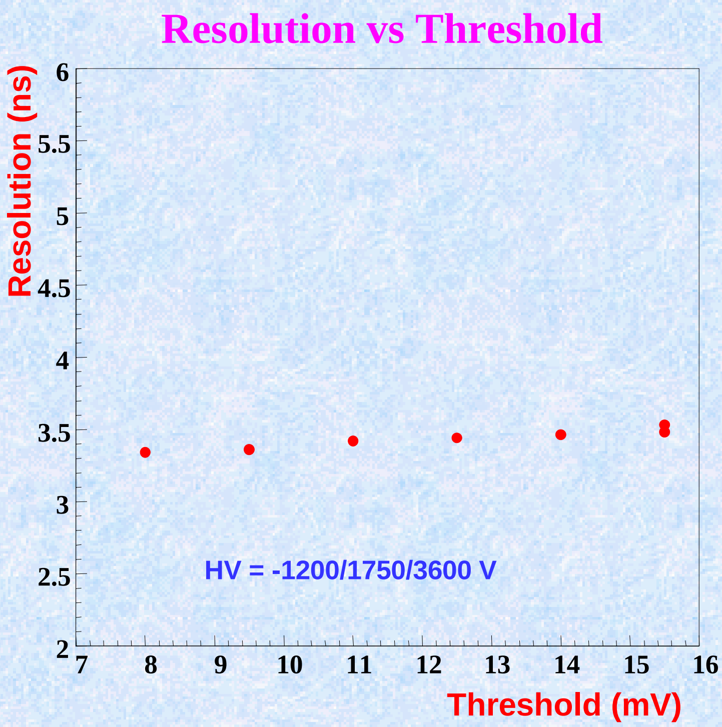


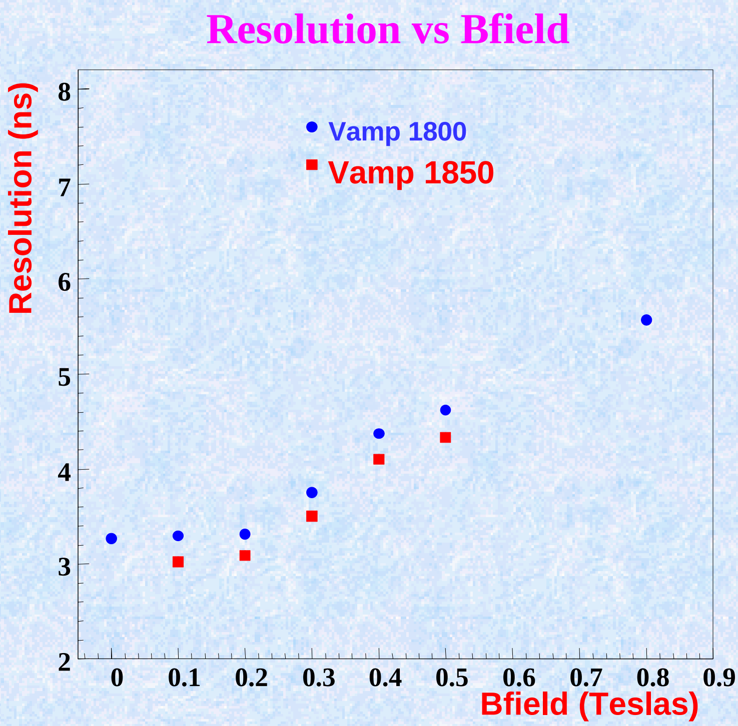

### Efficiency vs Bfield



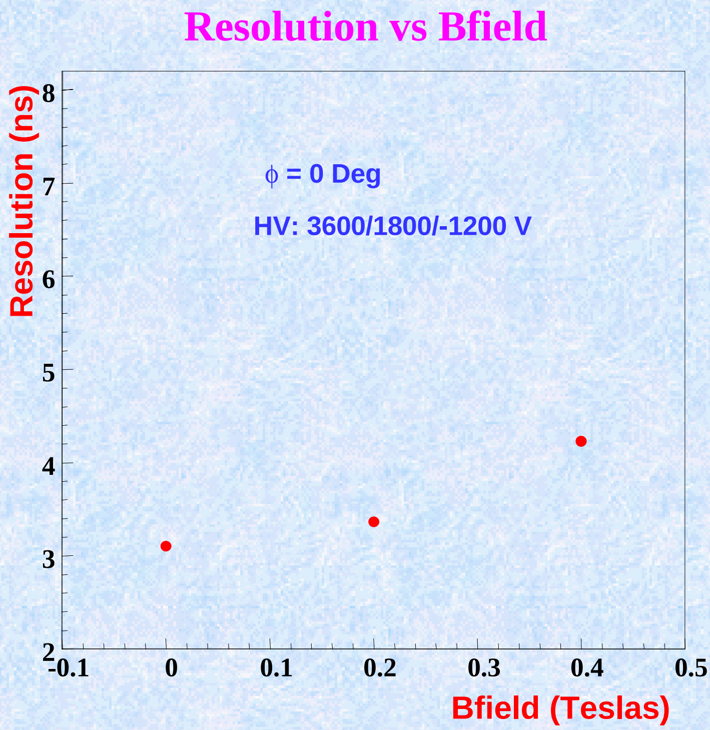
# MAD on Beam

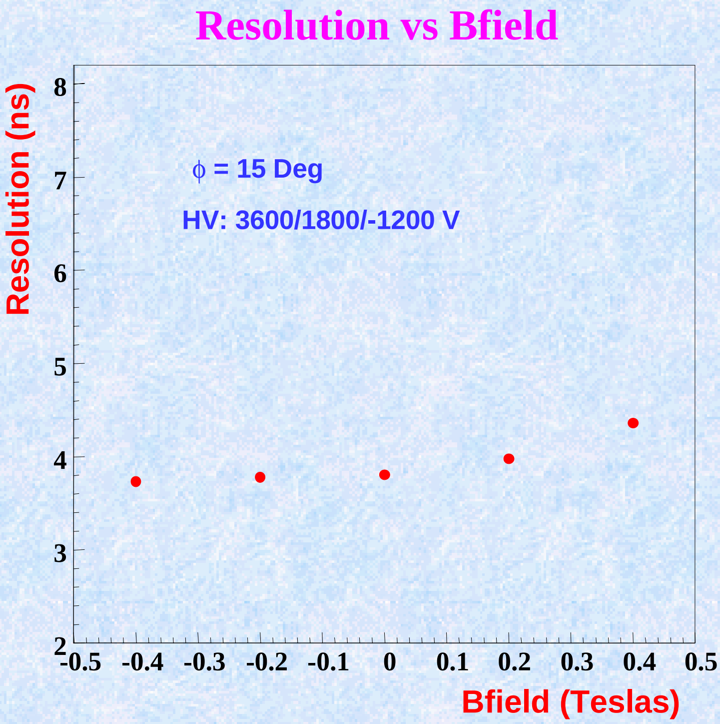
## Resolution vs Threshold and Bfield




Preliminary results - raw data plots



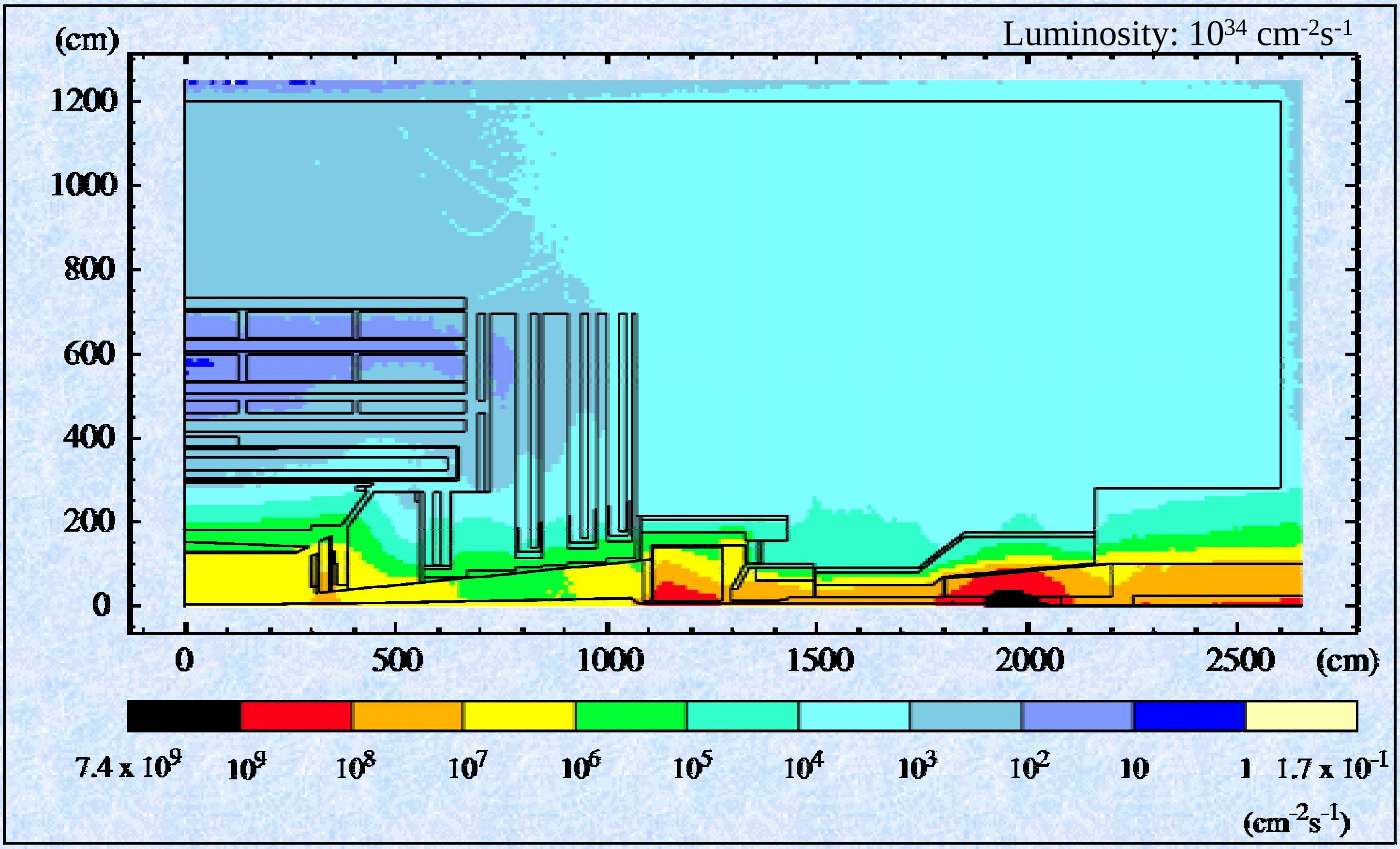
# RADIATION TESTS

## 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

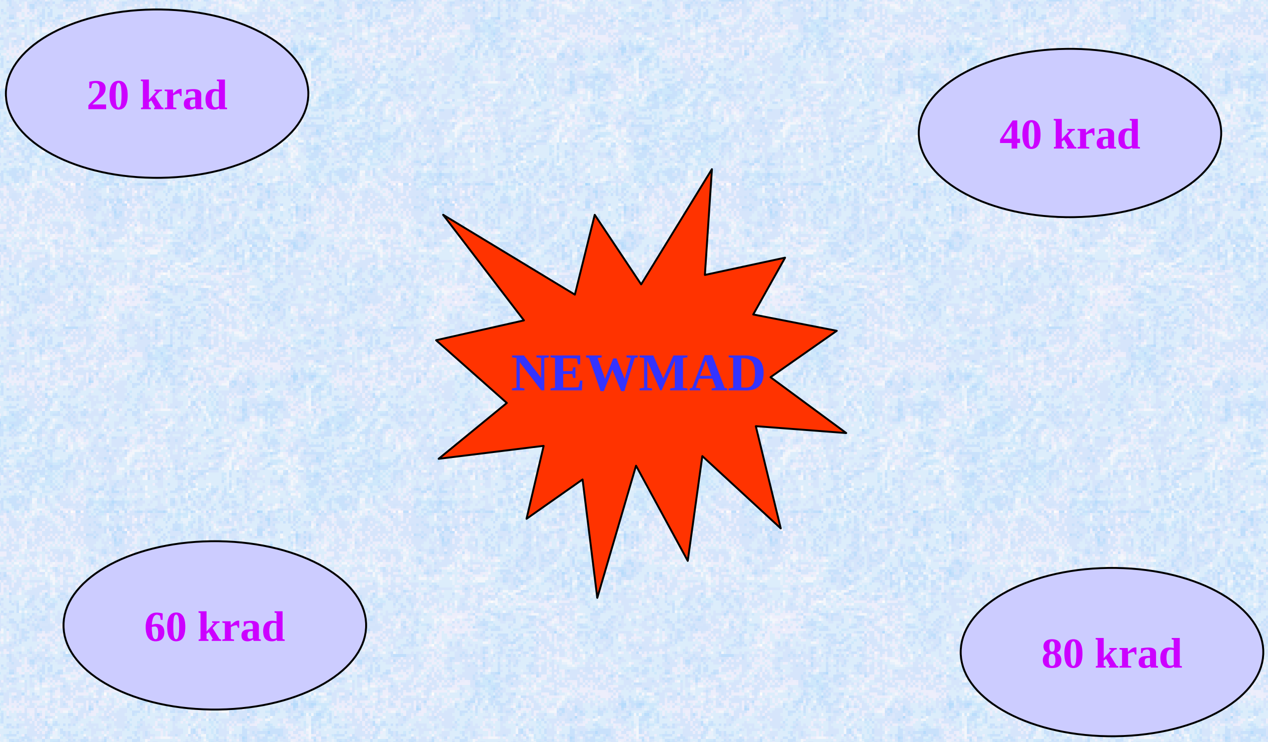
For best ASIC characterisation
gamma irradiation is tested too
(in CMS barrel the expected flux is below 10krad)

# RADIATION TESTS

## Gamma rays Irradiation

$^{60}$Co source

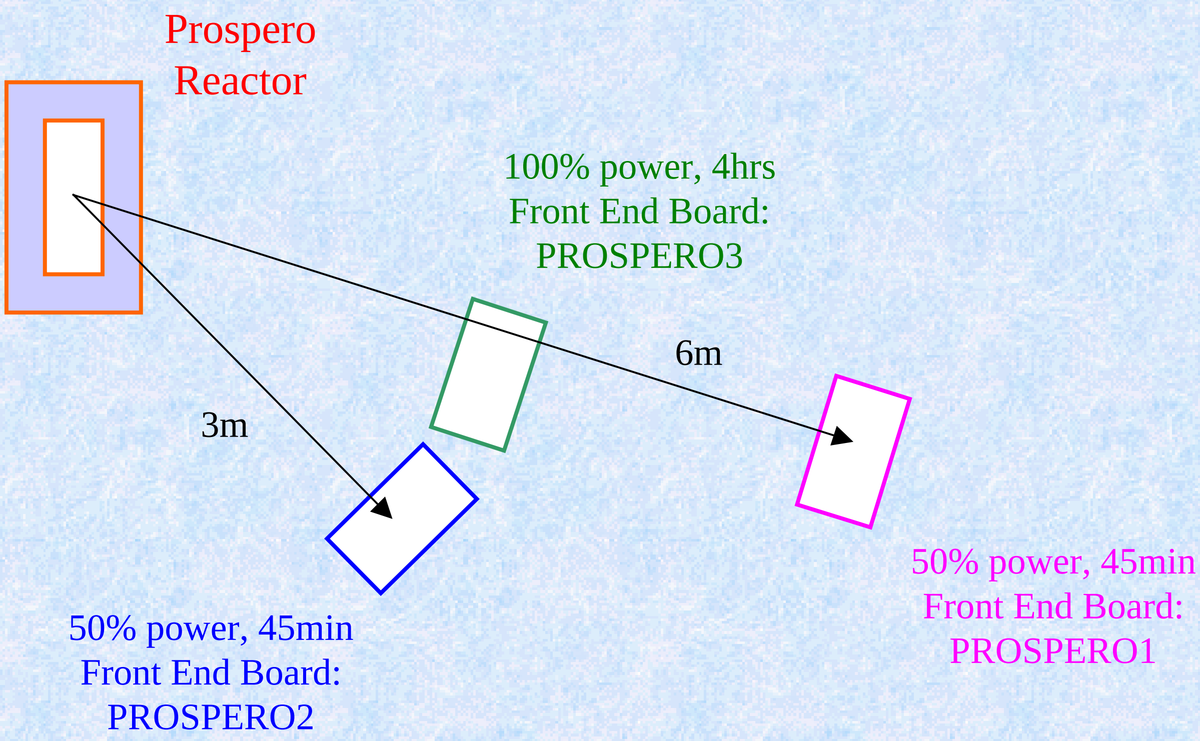
4 NEWMAD prototypes exposed to gamma rays at Bologna




NO dynamic or static changes measured!

# RADIATION TESTS

## Fast Neutrons at PROSPERO Facility

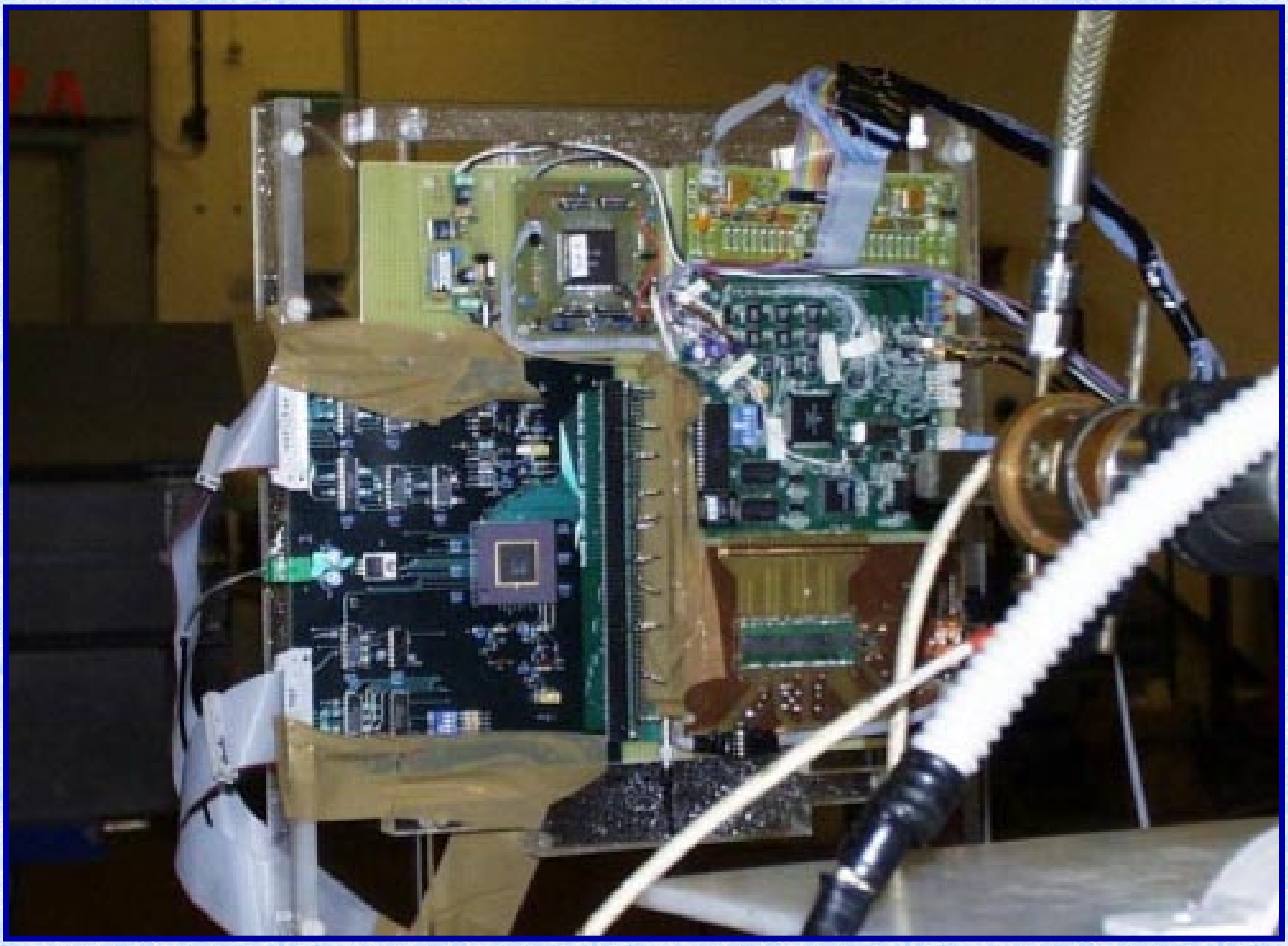



| FRONT END BOARD | REACTOR DISTANCE | $n/cm^2$ EQ. 1MeV(SI) |
|---|---|---|
| PROSPERO1 | 6m | **$4.85\ 10^{10}$** |
| PROSPERO2 | 3m | **$1.53\ 10^{11}$** |
| PROSPERO3 | 3m | **$1.72\ 10^{12}$** |

NO dynamic or static changes measured!

# RADIATION TESTS

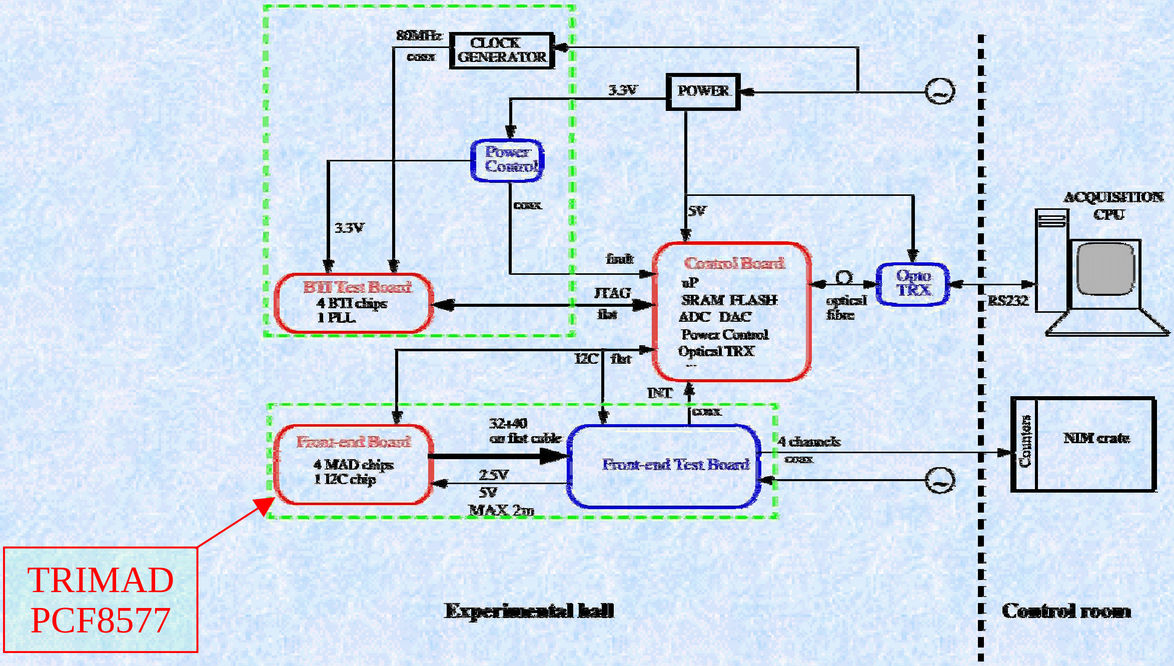
## SE induced by Fast and Slow Neutrons at LNL



**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$^2$

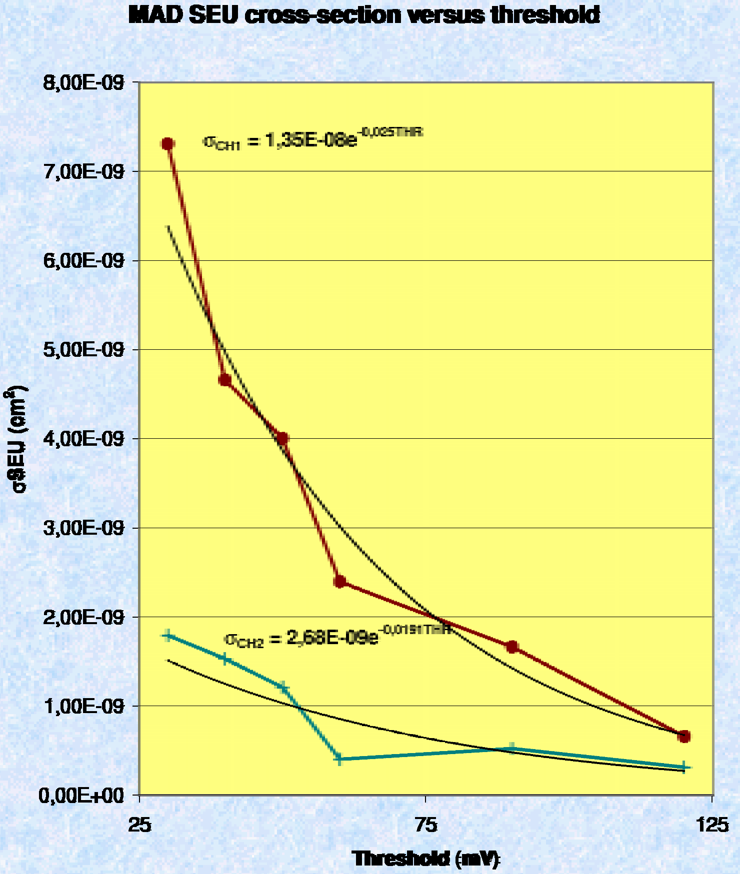
Fast Neutrons (up to 10 MeV)

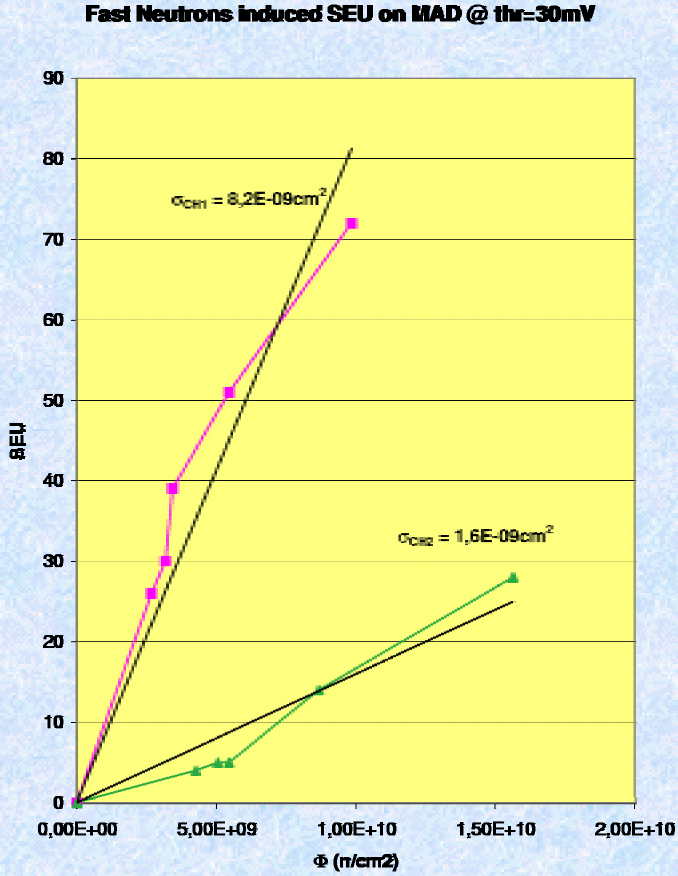
⇨ $^9$Be(d,n)$^{10}$B reaction — 4.0/6.3 $10^{10}$ n/cm$^2$

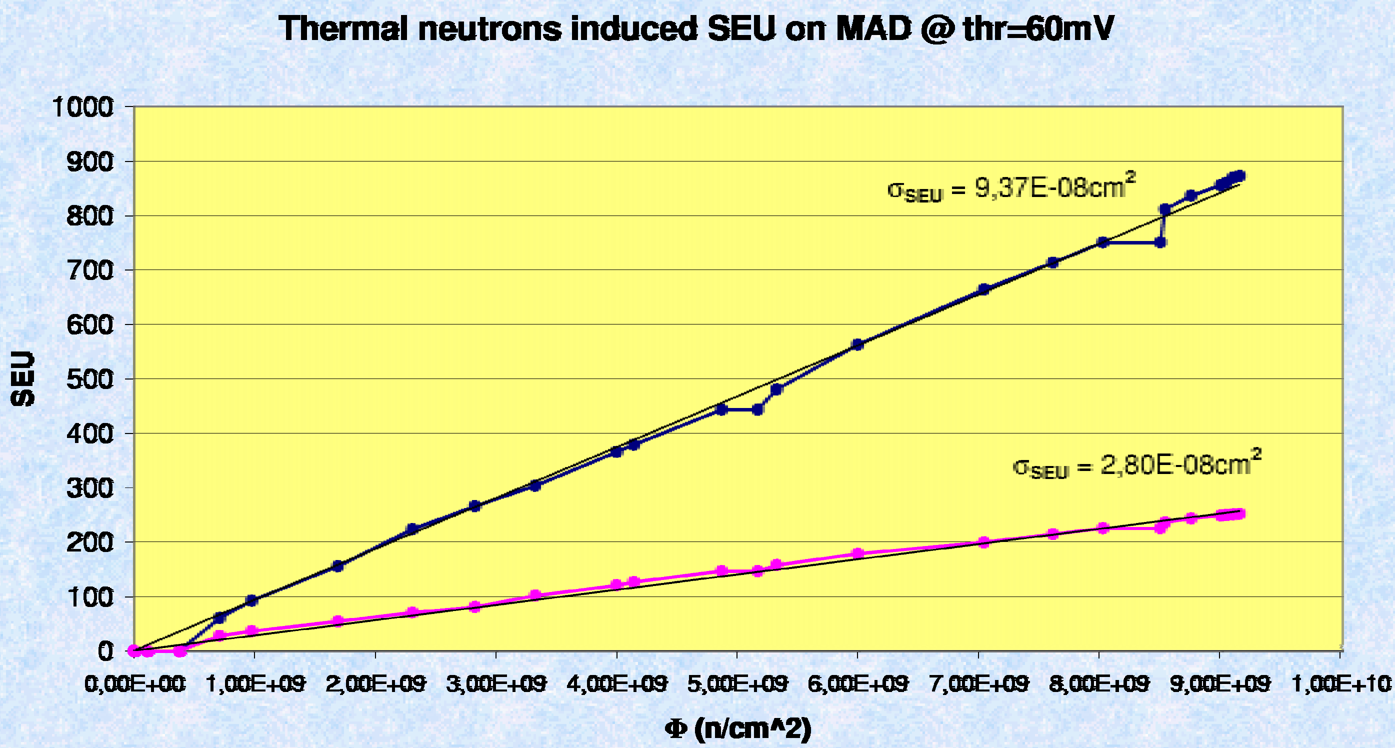
NO changes measured on MAD and I$^2$C ICs!

# RADIATION TESTS

## SE induced by Fast and Slow Neutrons at LNL

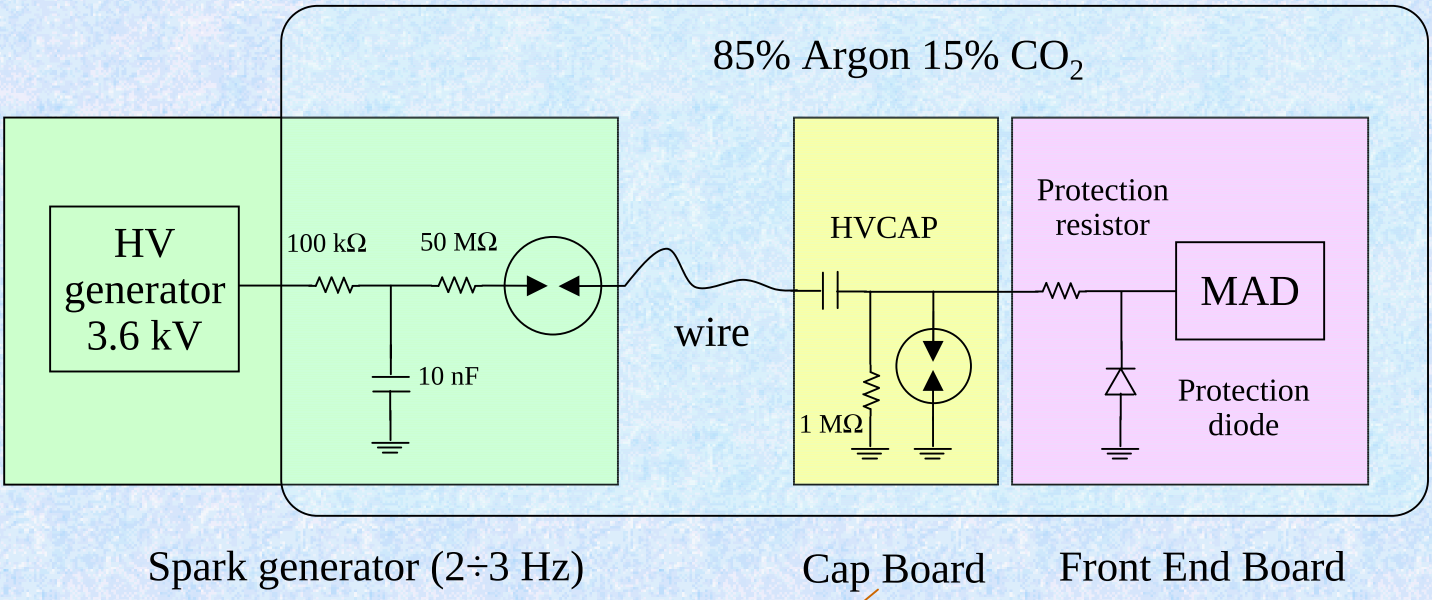


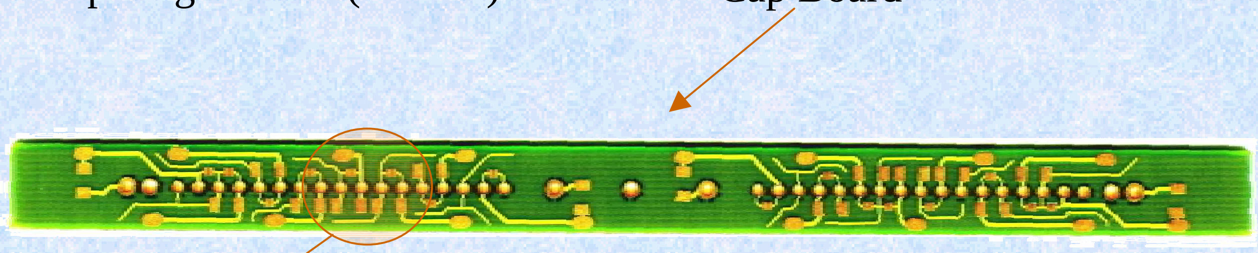



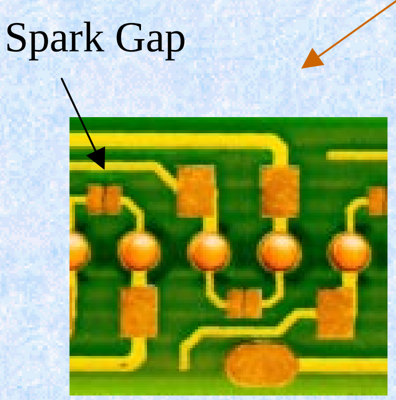



# DISCHARGES TESTS

## Drift Tubes discharges simulation



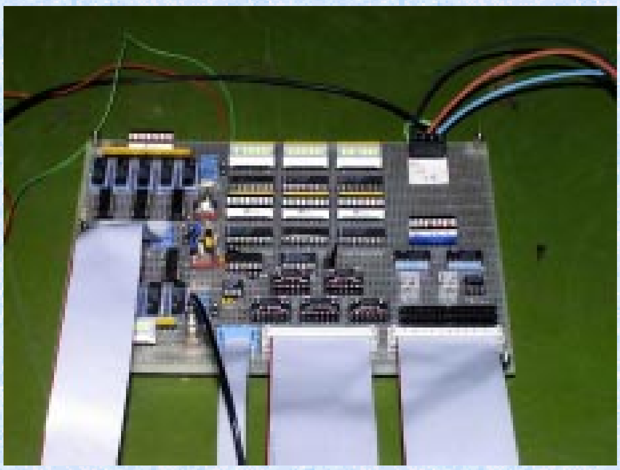



- Tests performed in gas $ArCO_2$ (85:15)
- protection resistor of 39 Ω
- BAS678 protection diode
- HVCAP of 470 pF

- 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:

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

*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

| $T_{op}$ (ºC) | $T_{test}$ (ºC) | *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.**