The LHCb Muon System

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On behalf of LHCb muon group:
CAGLIARI, CBPF, CERN, LNF, FERRARA, FIRENZE, PNPI, POTENZA, ROMAI, ROMAII

Outline:

- Overview of the LHCb Muon Detector
- Detector requirements
- Chamber design and specifications
- Chamber construction and quality control
- Conclusions

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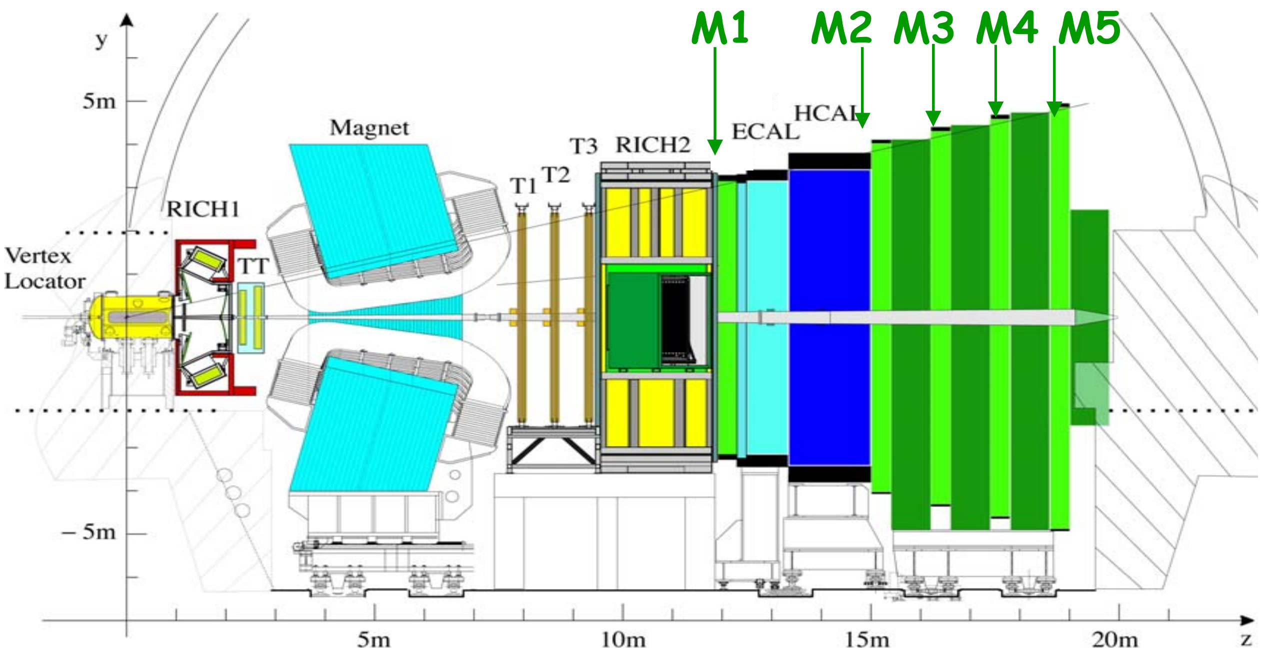
Muon system overview

Purpose: muon triggering and offline muon identification



5 Muon stations M1 in front and M2-M5 behind the calorimeters

Angular acceptances:
20 (16) – 306 (258) mrad in bending (non-bending) plane
--> geometrical acceptance of ~ 20% for muons from b decays

435m² of detector area with 1380 chambers

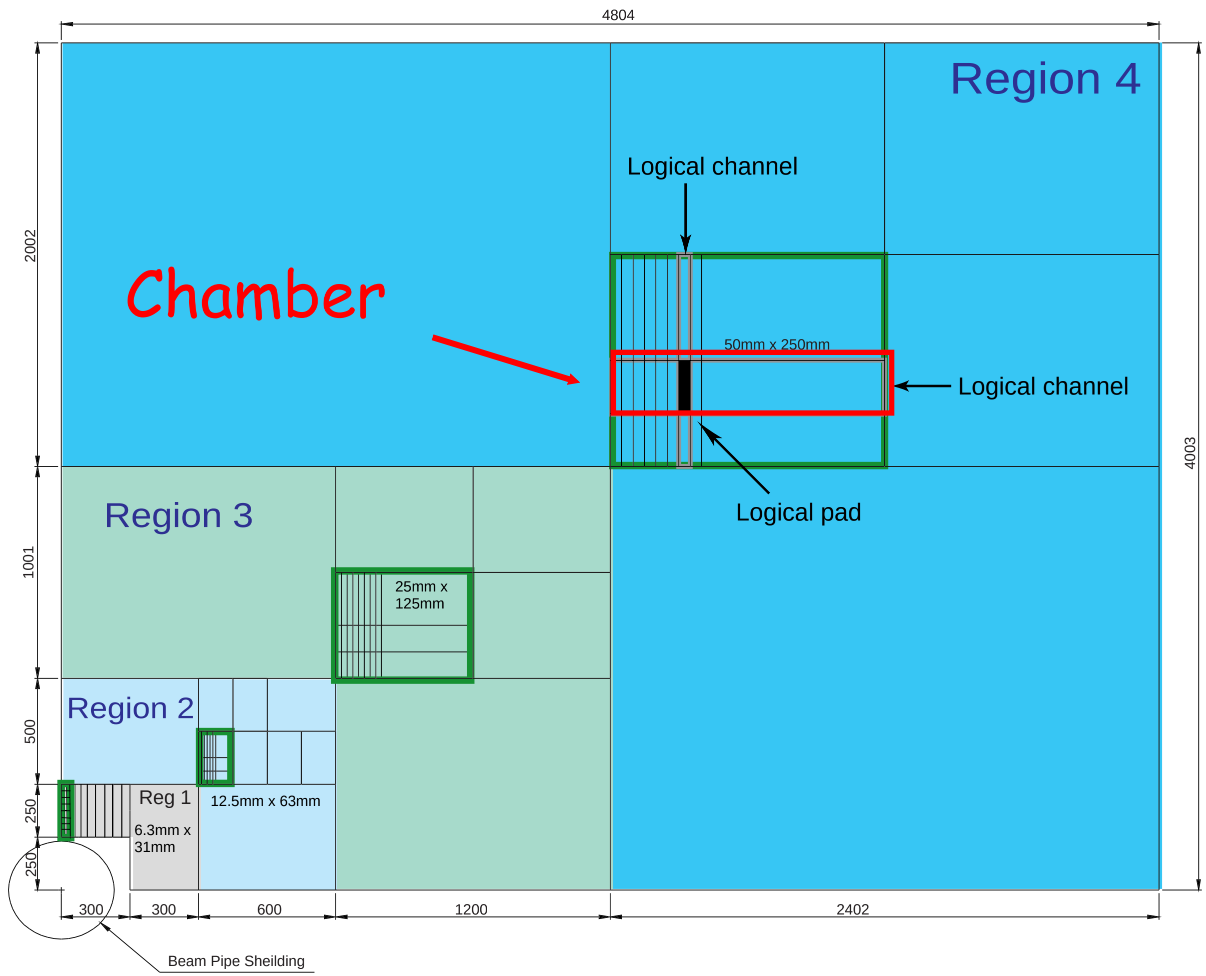
Requirements

Provide a fully efficient and robust level-0 high Pt muon trigger (through a 5-fold coincidence of hits in all stations) and bunch crossing identification:

- Good time resolution => high efficiency (>99%) per station in a time window of 20ns (96% in M1)
- High rate capability => up to 0.5 MHz/cm^2 for inner chambers at $L = 5 \times 10^{32}\ cm^{-1}\ s^{-1}$
- Good ageing resistance over 10 years
- Good spatial resolution => pt resolution of triggering muons < 20%

The Muon system

- 4 Regions/Station
- Granularity shaped according to particle density
- 20 different chamber dimensions for a total of 1380 chambers, mainly MWPC
- M1R1 → triple-GEM
  - area = 1 m² but 20% of triggering muons
  - challenging for ageing, rate and time resolution



GEM detector: principle of operation

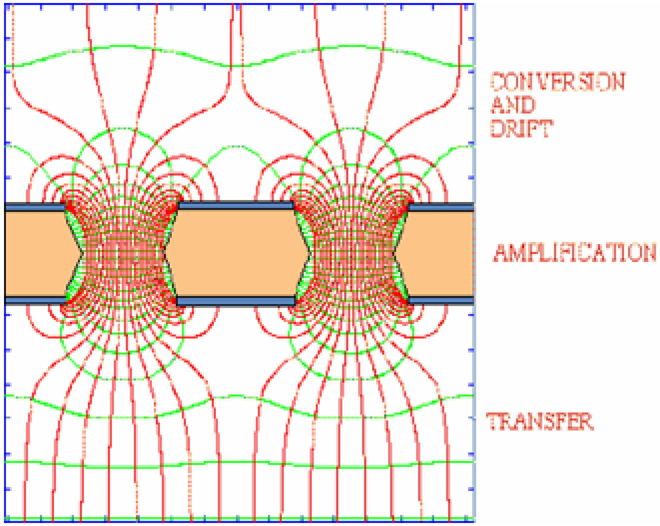
The GEM (Gas Electron Multiplier) is a thin (50 μm) metal coated kapton foil, perforated by a high density of holes (70 μm diameter, pitch of 140 μm)

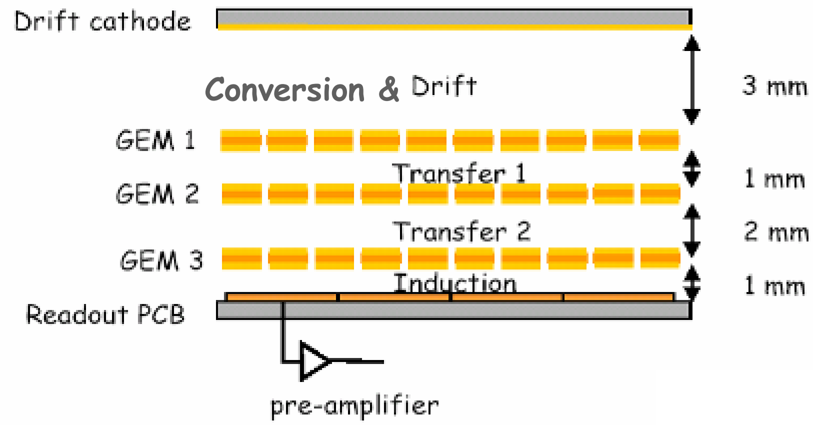
By applying 400-500 V between the two copper sides, an electric field as high as ~100 kV/cm is produced into the holes which act as multiplication channels.

Gains up to 1000 can be easily reached with a single GEM foil. Higher gains are usually obtained by cascading two or three GEM foils.

A Triple-GEM detector is built by inserting three GEM foils between two planar electrodes, which act as the cathode and the anode.

But huge R&D on detector was needed!

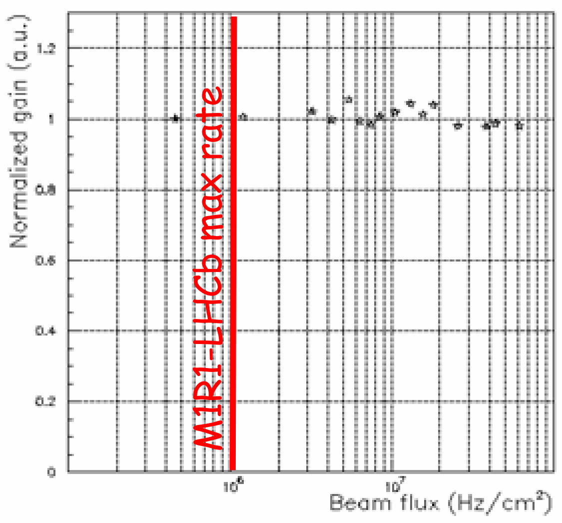




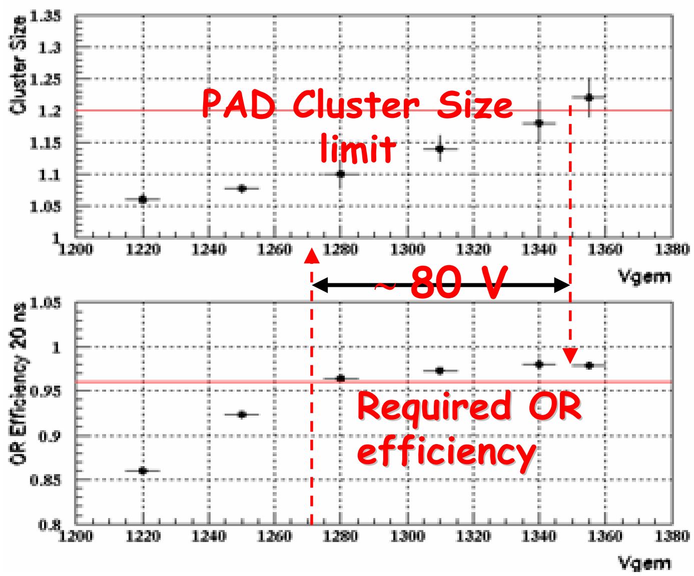
GEM detector in M1R1

Rate Capability ~ 1 MHz/cm^2 @ $5*10^{32}$ $cm^{-2}s^{-1}$
Station Efficiency > 96% in a 20 ns time window
PAD Cluster Size < 1.2 for a 10x25 mm^2 pad size
Radiation Hardness ~ 1.6 C/cm^2 in 10 years @$6x10^3$
Gas mixtures $Ar/Co_2/CF_4$ (45/15/40)
Time resolution up to 2.9 ns (rms)

Required efficiency in 20 ns time window is achieved with 2 chambers in "OR"



Good rate capability up to 50 MHz/cm^2 !!

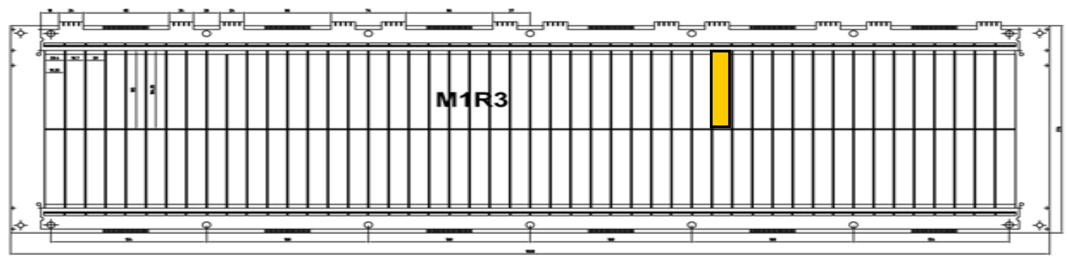


80 V → factor 3 in gain

MWPC readout schemes

Different readout schemes depending on the granularity requested from trigger and offline and on the particle rates

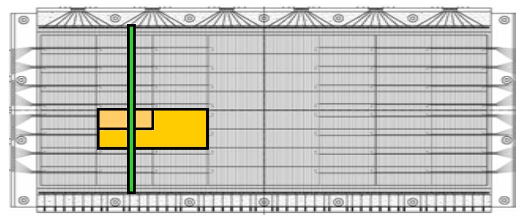
Region 4: Anode wire readout



Region 3: Cathode pad readout

Granularity goes from $(1 \times 2.5)\ \mathrm{cm}^2$ to $(25 \times 30)\ \mathrm{cm}^2$

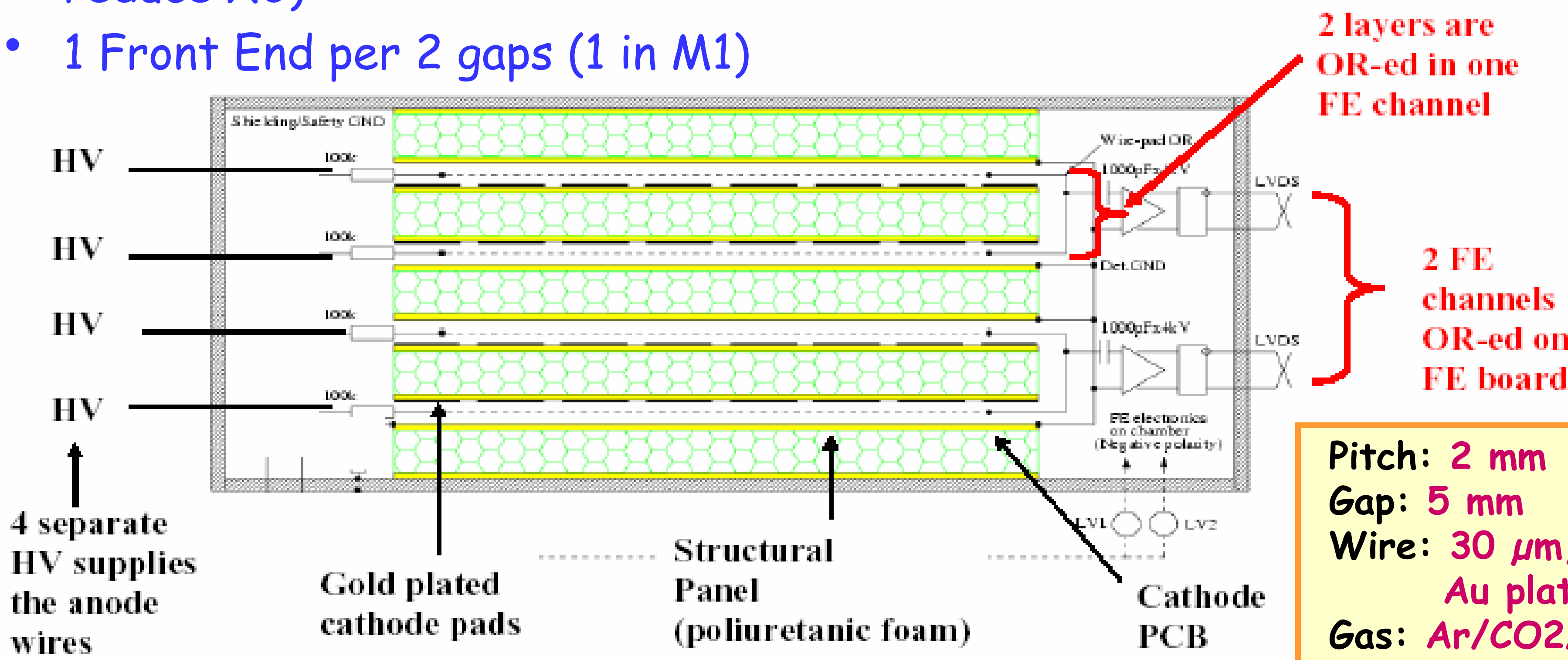
MWPC dimensions from $(20 \times 48)\ \mathrm{cm}^2$ to $(149 \times 31)\ \mathrm{cm}^2$



Region 1+2: (in stations M2+M3)
Combined anode and cathode readout

MWPC Design

- Multi Wire Proportional chambers with 4 gas gaps (2 gaps in M1 to reduce X0)
- 1 Front End per 2 gaps (1 in M1)



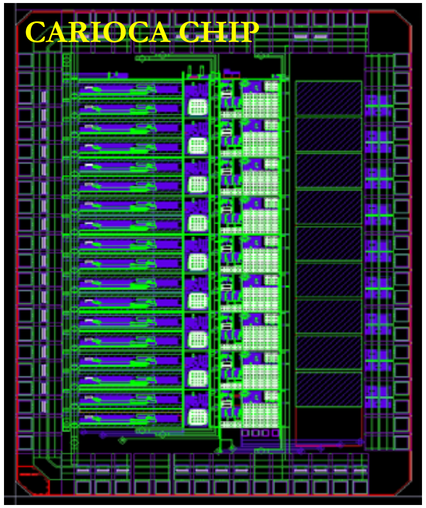
Pitch: 2 mm
Gap: 5 mm
Wire: 30 μm, Au plated W
Gas: Ar/CO2/CF4 (40/55/5)
HV: 2620 V
Gas Gain: 5×10^4

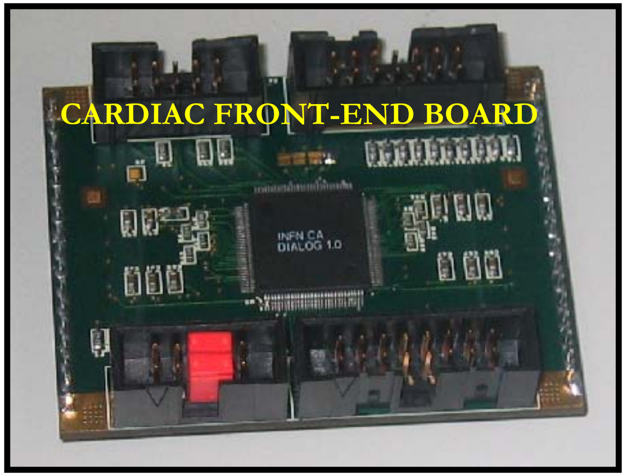
Front-End Electronics

CARIOCA is the Amplifier-Shaper-Discriminator front-end chip developed for MWPC of LHCb in 0.25 um CMOS radiation hard technology

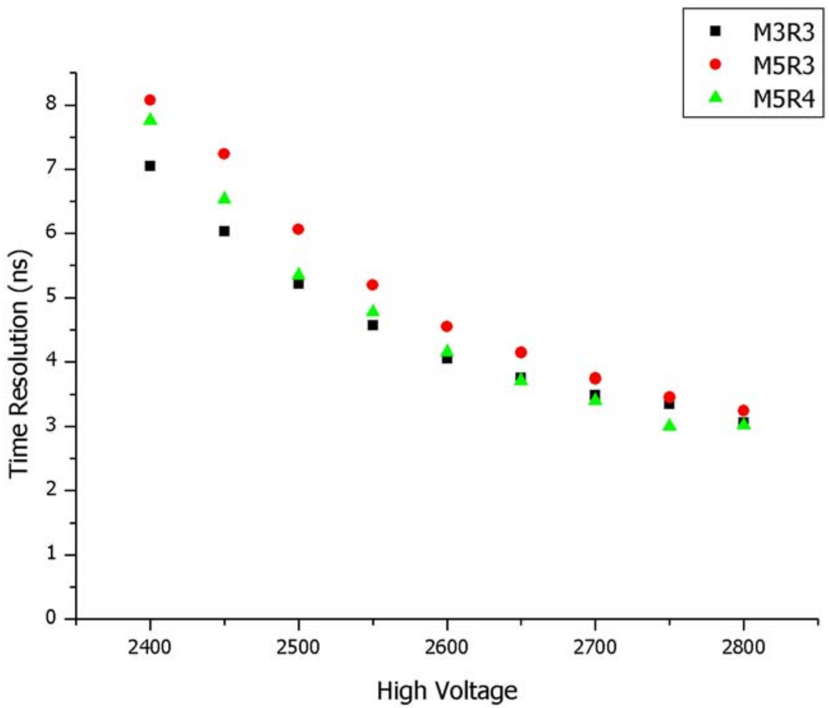
Specifications:

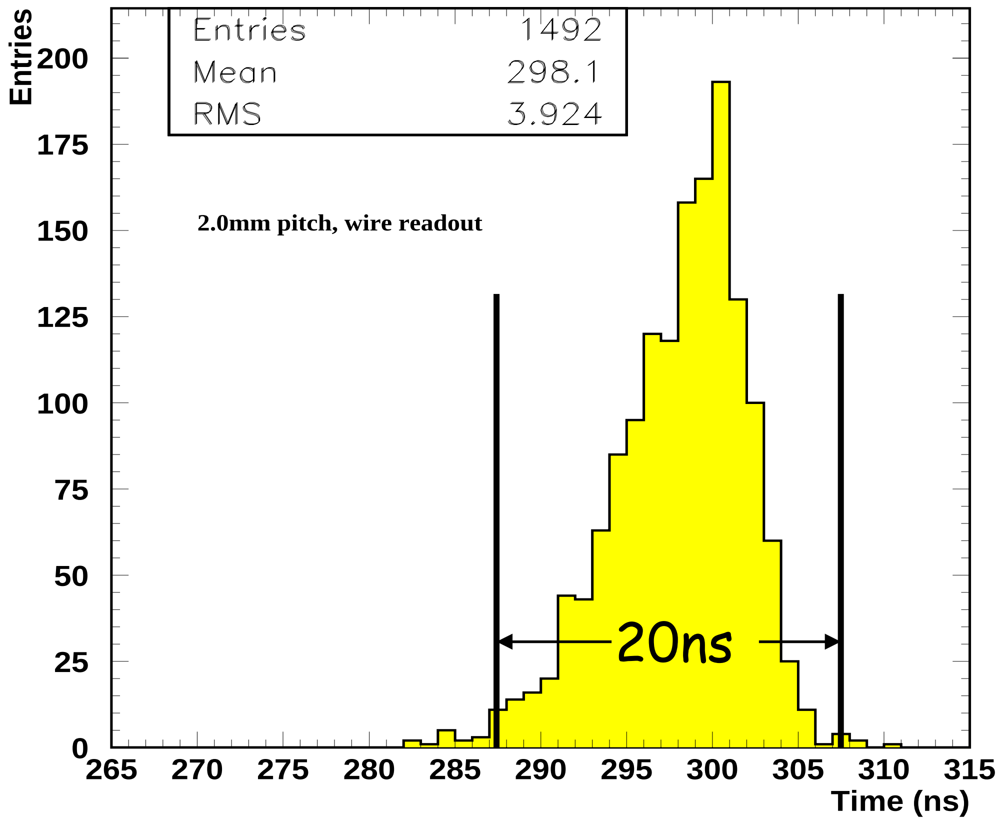
- short peaking time:
  $t_p \sim 10$ ns for $C_{det} = (40 \div 220)$ pF
- low noise:
  ENC ~ 2000 + 40 e-/pF
- high rate capability (up to 1MHz):
  pulse width ~ 50 ns, signal tail cancellation and baseline restoration circuits





Time resolution



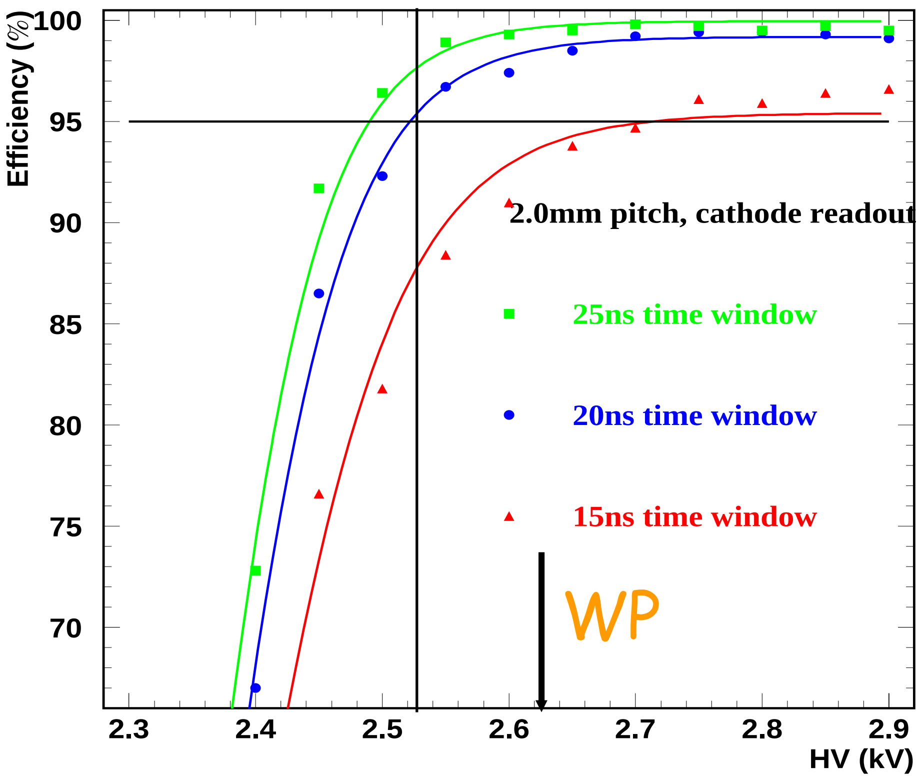


- Optimum amplifier peaking time ~10ns
- Intrinsic time resolution is less than 4ns

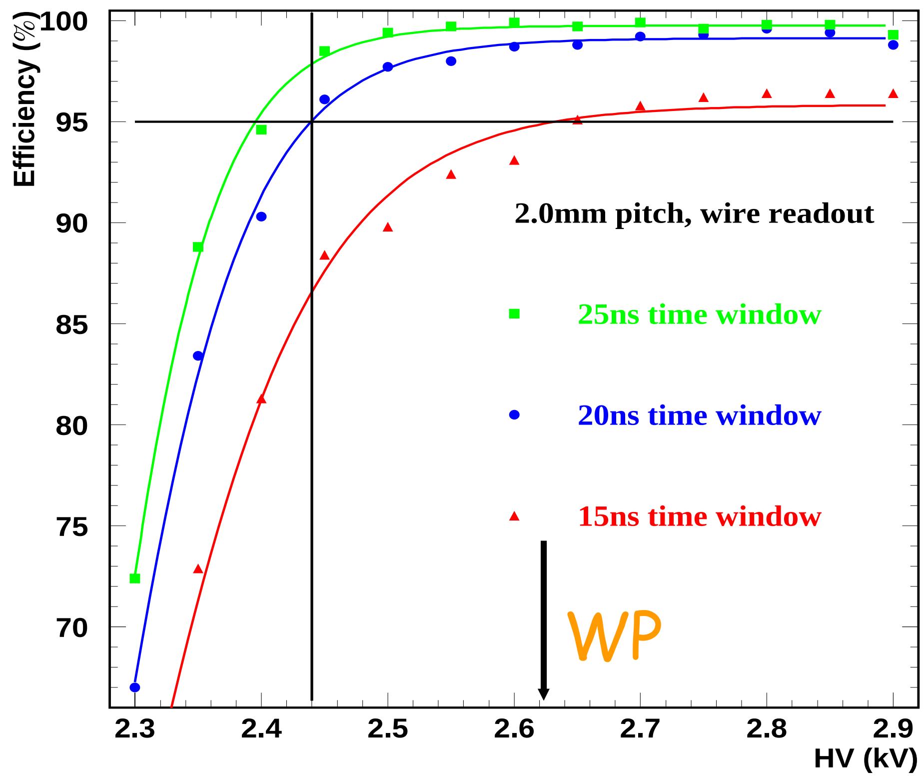
Chamber Efficiency

An efficiency per double gap > 95% is required. The logical OR of the two double gap ensures that ε > 99.8% per station will be reached.

Cathode Efficiency:

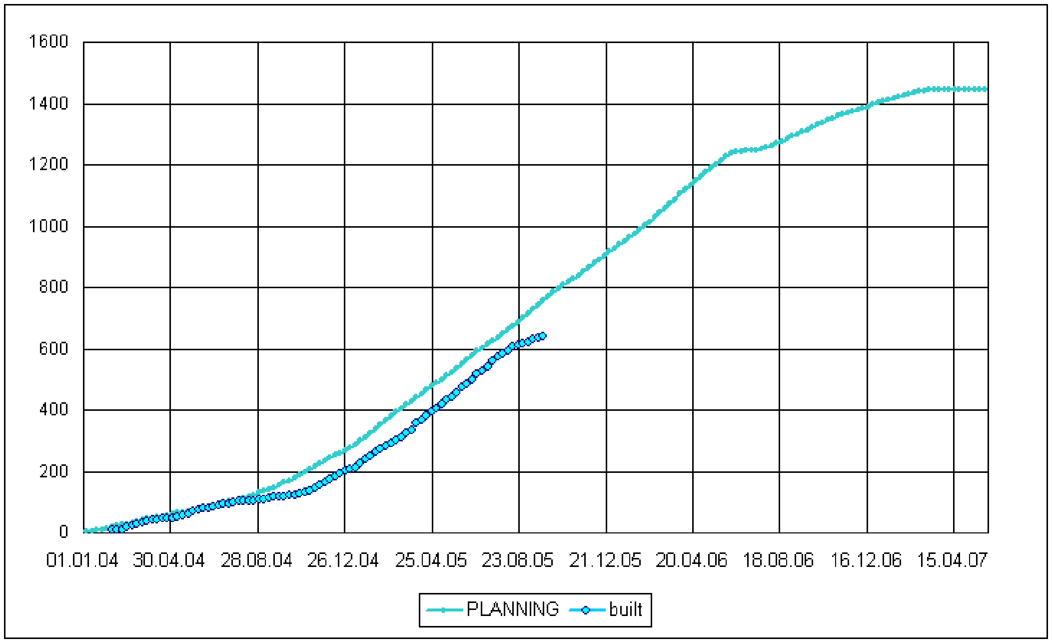


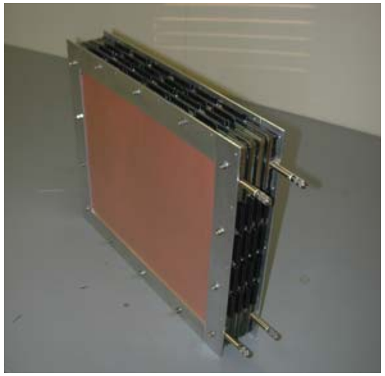
Anode Efficiency:



Status of construction

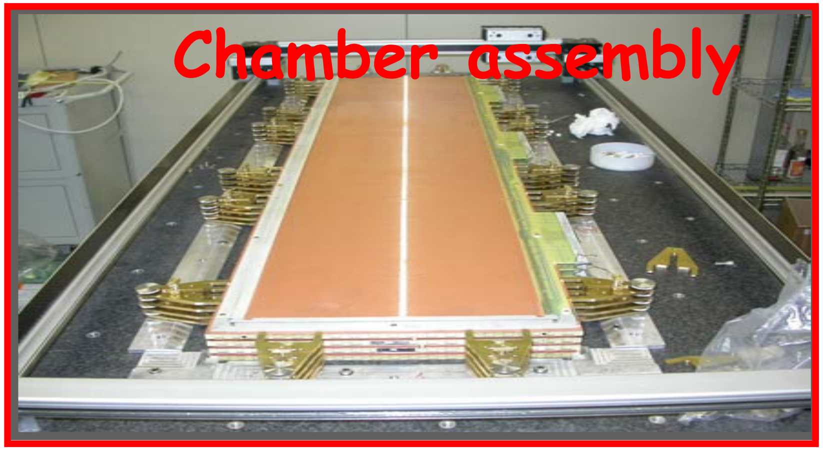
- within 2 years ~ 1400 chambers have to be built in 6 production centers
- ~ 45% of the chambers have been produced
- Quality assurances (QA) is a key issue: test on 100% of production





Chamber construction

1368 chambers -> automatic tools:



Chamber specifications

Gas Gain variations:

Working point should not move out of the voltage plateau:
from test-beams: plateau width ~ 150 V for 4-gap

lower limit ε>99% (2.55KV), upper limit: cluster size < 1.2 (2.7KV)

→ Working point = 2620 V

➔ Good bi-gap: maximum voltage change of ±50 V that corresponds to a gain change of a factor 1.4 ➔ double gap gain on 100% of area between [$0.7G_0$, $1.4G_0$], where G_0 is the 4-gap average

→ What chamber imperfections are allowed with this constraint?

Quality controls

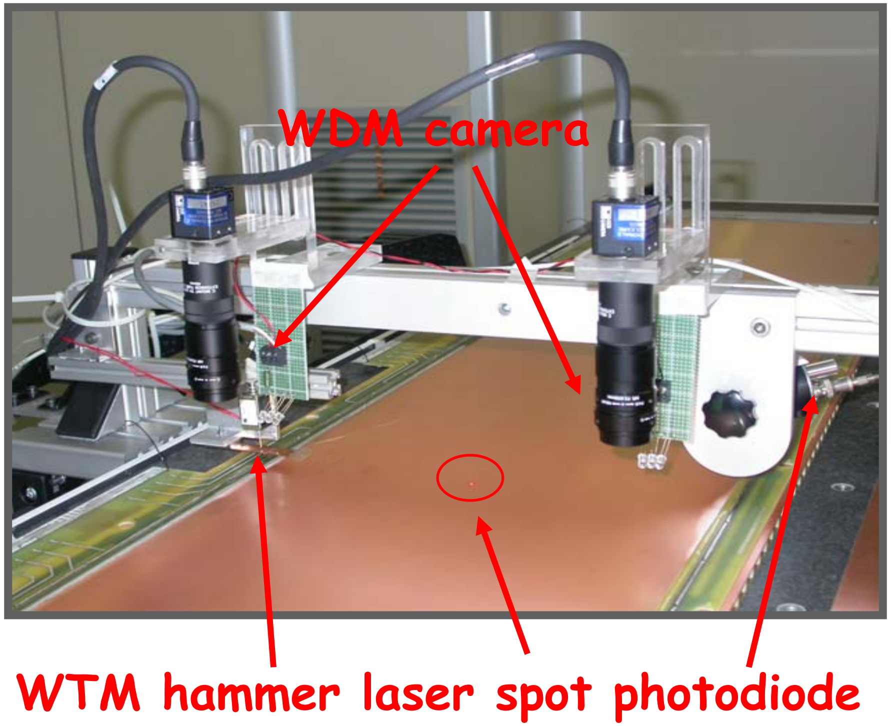
Panel test:

- Panel planarity: min 95 % of the surface within 50 μm,
  Max deviation < 100 μm
- Wire fixation bars thickness (half gap): min 95% within [2.45, 2.55] mm,
  all points within [2.42,2.58]
- Wire Pitch: min 95% within [1.95, 2.05] mm, all points within [1.90, 2.10]
- Wire Tension: all tension higher than 50 g, Max deviation < 0.1 T_0

Chamber test:

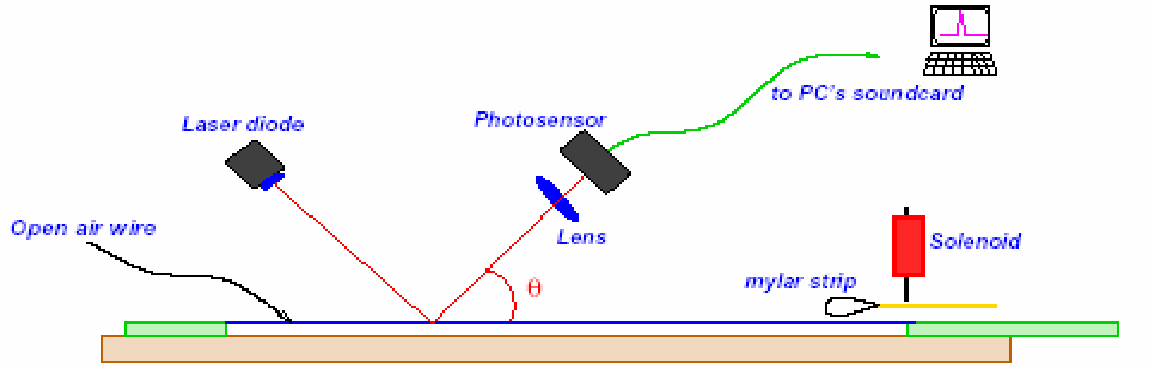
- Gas Leak Rate: leak rate < 2 mbar/hour (@5 mbar over pressure)
- HV Conditioning and test: dark Current < 10 nA per gap
- Gas Gain Uniformity: double gap gain between [$0.7G_0$, $1.4G_0$]
- Cosmic rays test: detection efficiency > 95% in a 20 ns time window

Wire tension (1)



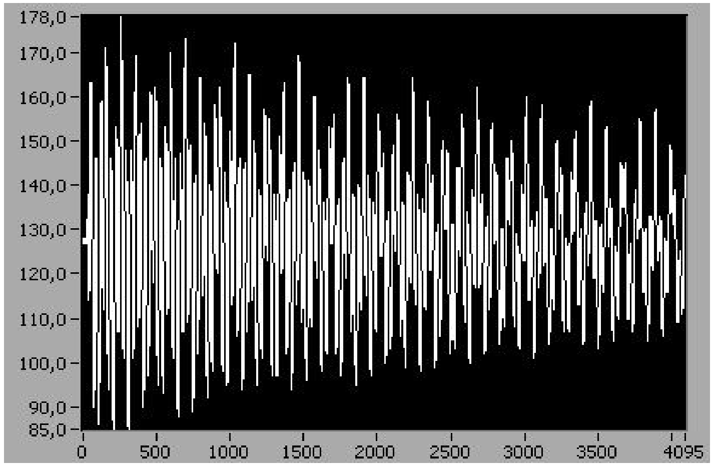
$$T = 4\mu l^2 f_0^2$$

Ferrara/Firenze

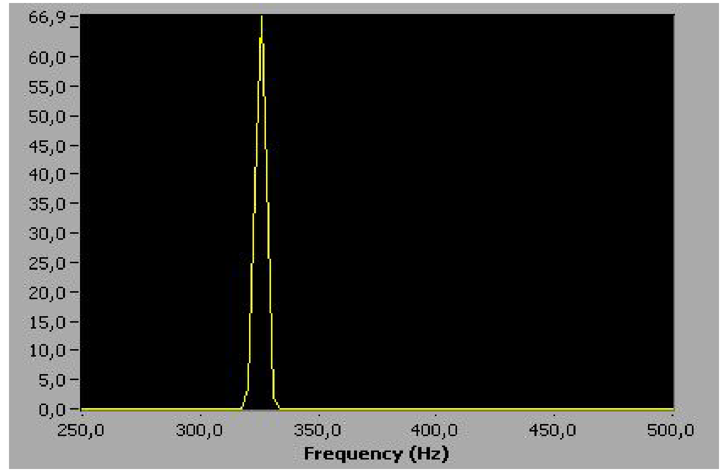


The wire, mechanically excited by a mylar hammer, vibrates with its own fundamental frequency; the light of a laser beam is reflected on the wire and then detected by a photodiode whose signal is sent to a standard PC sound card and then analyzed

Wire tension (1)

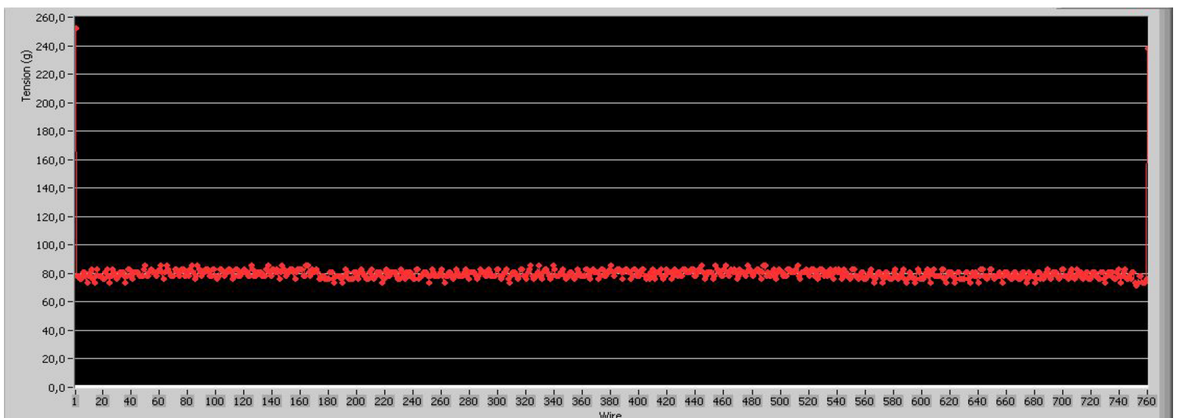


Time waveform



Fast Fourier Transform

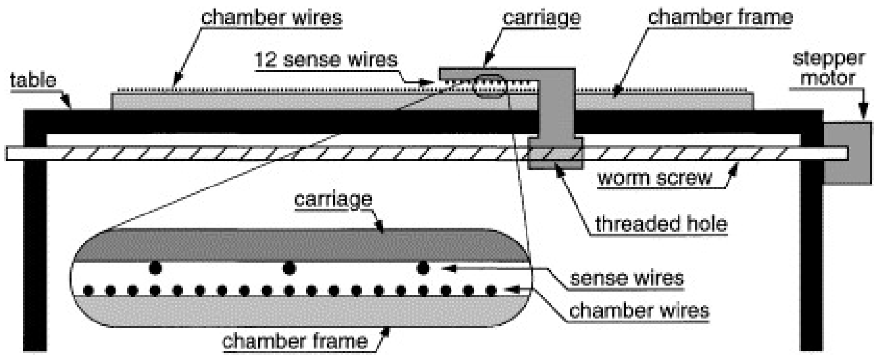
Tension (g)



Wire number

About 4 sec/wire with an accuracy of 0.2%

Wire tension (2)



The wire is forced to oscillate by a periodic HV applied to a sense wire place parallel and close to it.

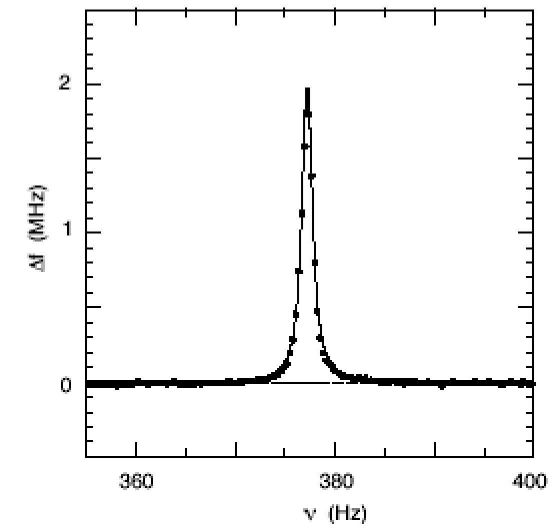
Maximum ΔC is automatically measured by a digital electronic circuit

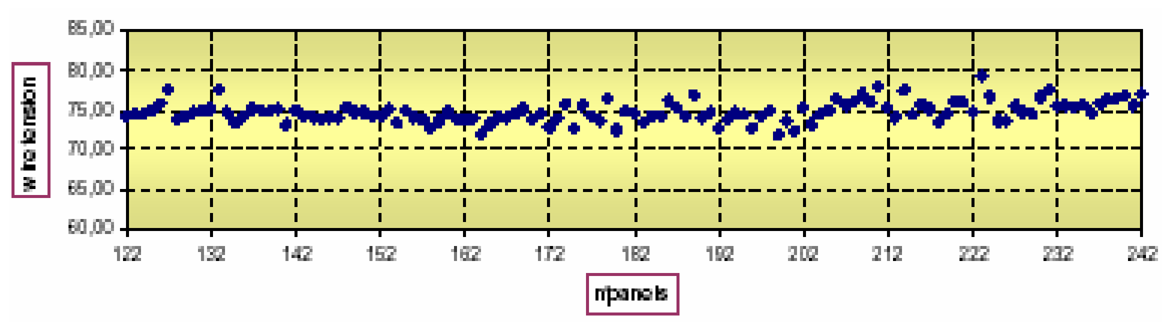
12 wires measured in parallel

→ 1300 wires/hour

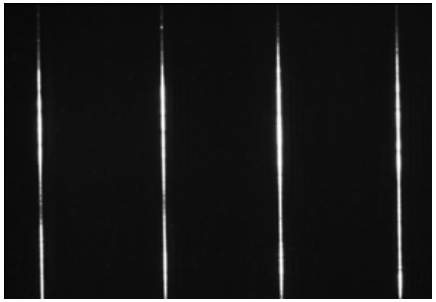
CERN, LNF, PNPI

Example of wire mechanical resonance peak:

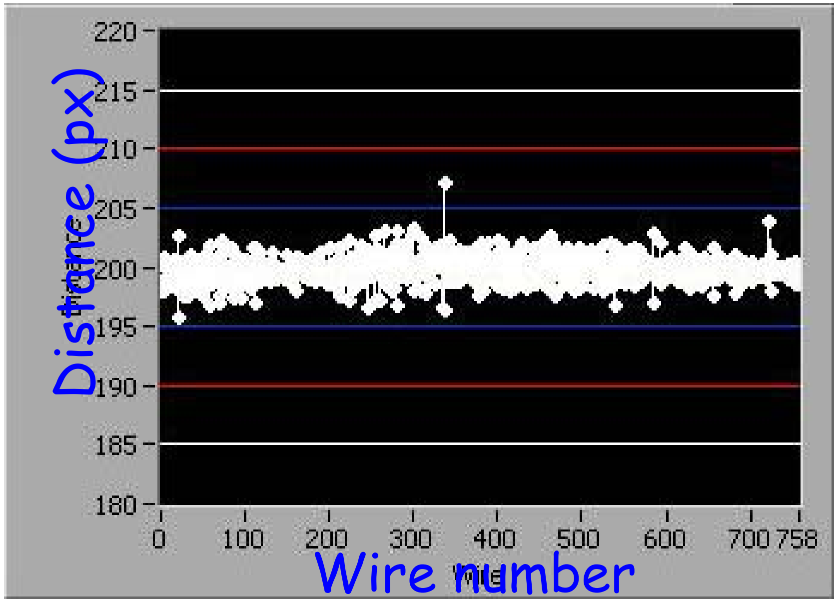


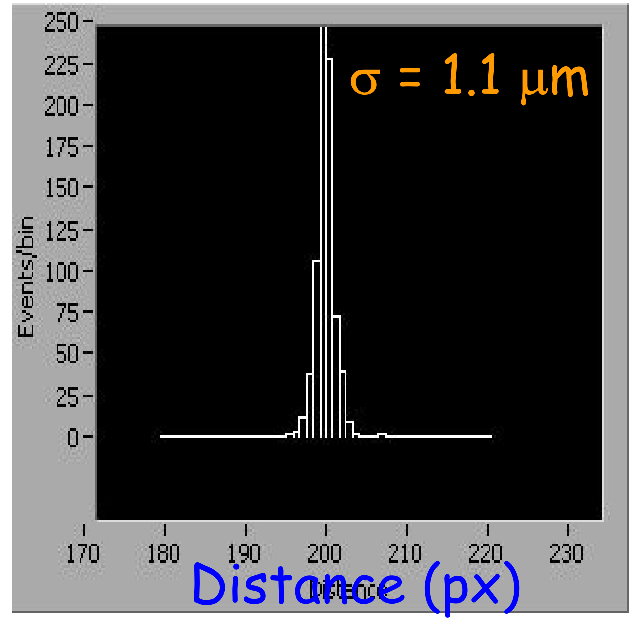


Wire pitch



Measurement of wire pitch with CCD cameras

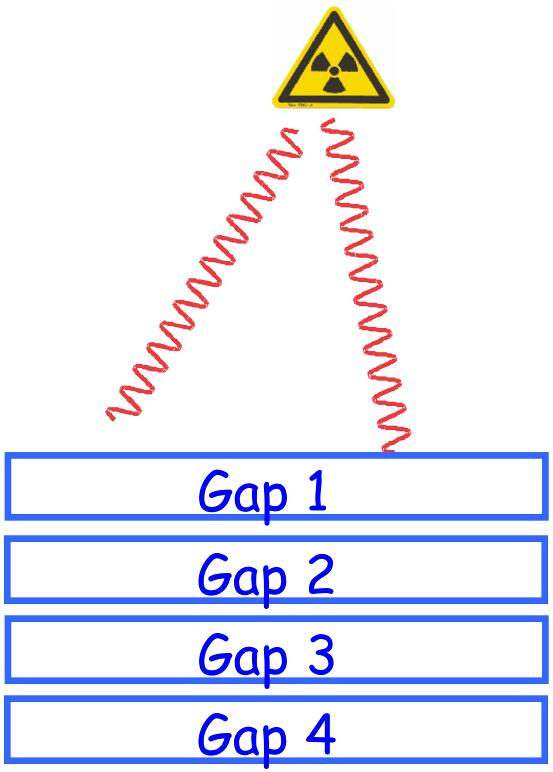




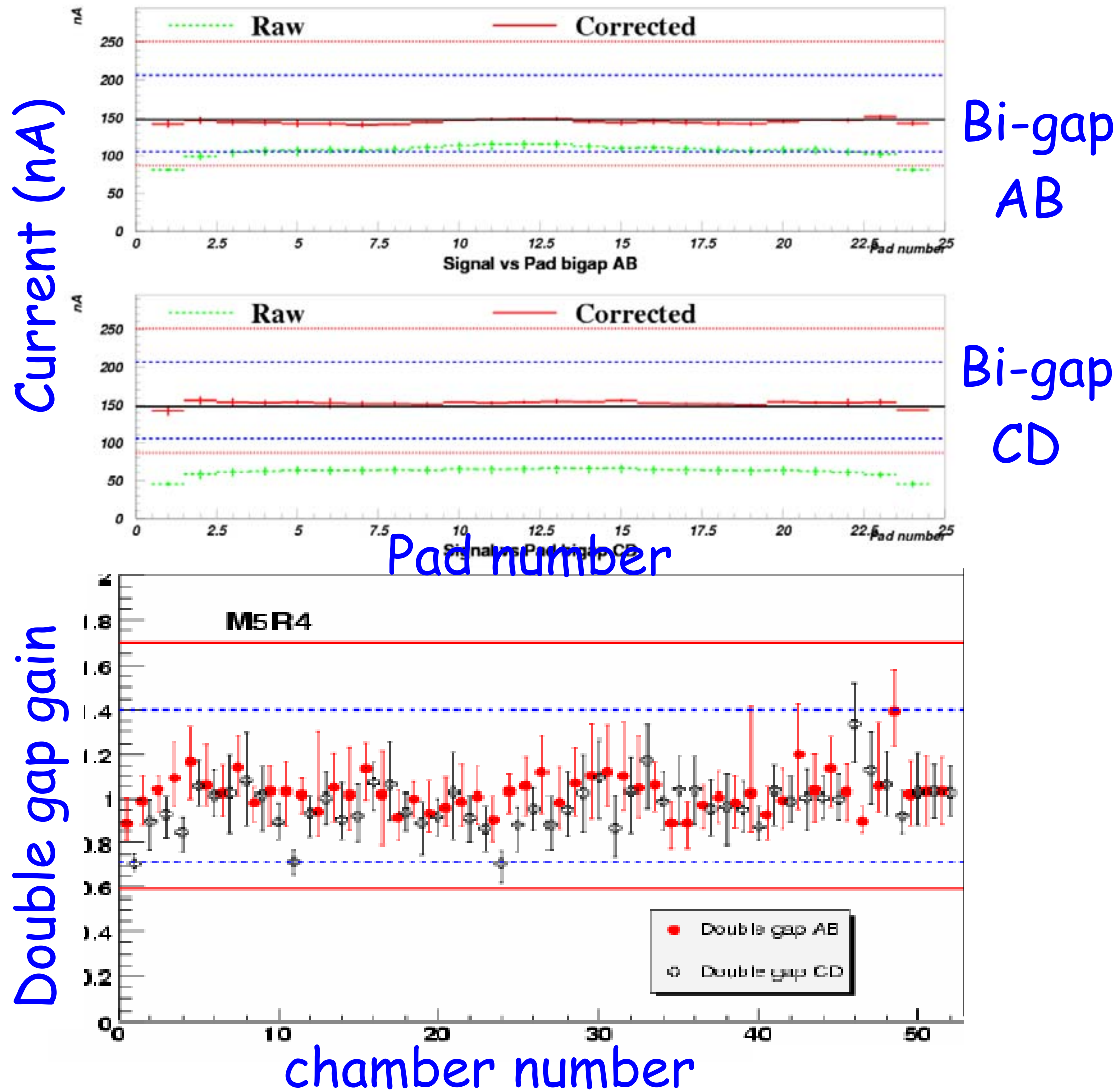
Reproducibility of result within 1.5μm (RMS) on average

-> Method well adapted for reliable QA

Gas gain uniformity

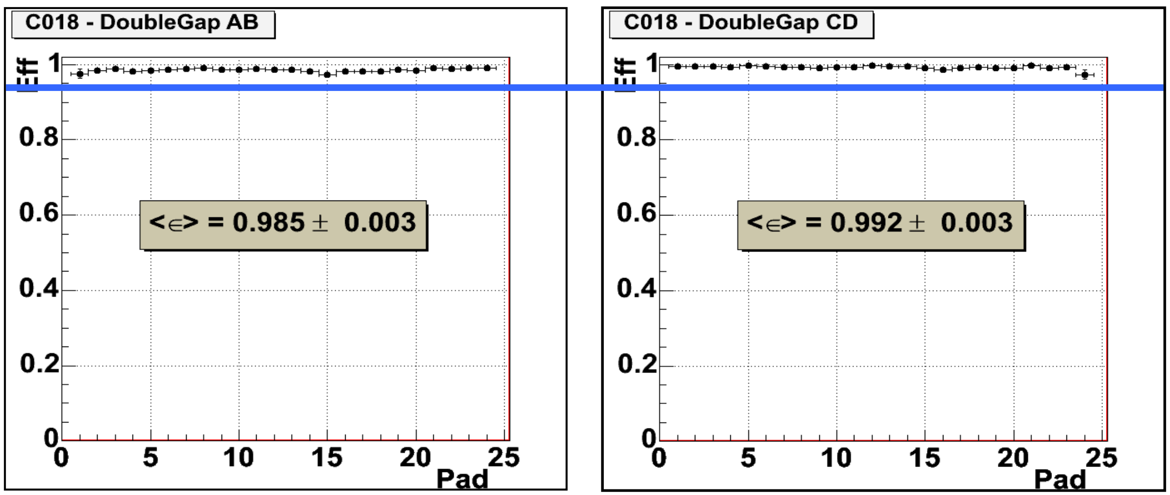


Corrections are applied for electron attenuation in different gaps and edge effects



Cosmic ray test

- 2 scintillator planes provide the triggers.
- 4 chambers read out: 8 tracking layers.
- 7 double-gaps are used to reconstruct the tracks and evaluate the efficiency of the 8th double-gap.



← 95%

All tested double-gap are well above the 95% threshold
→ chamber efficiency > 99% !!!

Summary

- The LHCb Muon detector requirements are good time resolution, high efficiency, high rate capability, aging resistance
- Extensive test have shown that our design of MWPC satisfies all the requirements
- A trigger efficiency of 46% for $b \rightarrow \mu X$ in the geometrical acceptance
- All chambers are tested with automatic procedures
- Construction is well advanced and the detector should be ready for the 1st LHC beams