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The LHCb Muon System

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on behalf of the LHCb collaboration

LHCb Muon Group:

Cagliari, CERN, Ferrara, Frascati, Marseille, PNPI,

Potenza, Roma 'La Sapienza', Roma 'Tor Vergata', UFRJ

LHCb Muon System

Outline:

- Introduction
  - Physics Goals and Requirements
  - Background Conditions
- Overview of the Muon System
  - Detector Layout
  - Detector Technologies
- Performance Studies
- FE-electronics
  - FE-chip
  - Electronics Architecure
- Planning and Conclusions

Introduction

Physics Goals:

- The Muon system of *LHCb* is primarily used as an identifier- and trigger system for muons produced in the decay of B-mesons: $B \rightarrow \mu X$;
  In particular: $B_d \rightarrow J/\Psi(\mu^+\mu^-) K_s$; $B_s \rightarrow J/\Psi(\mu^+\mu^-) \Phi$; $B_s \rightarrow \mu^+\mu^-$

- The muon momentum is measured precisely in the tracking system; the muon chambers are used to validate the muon candidate and match it with the track of the tracking system.

Requirements:

- Modest momentum resolution (~25%) for a robust P_T -selective trigger
- Good time resolution (few ns) for reliable bunch-crossing identification
- Good muon identification

Introduction

Background sources in the LHC environment:

- **Primary background**:

  - hadron punch-through including muons generated in the hadron shower
  - π,K $\rightarrow \mu$ X decays

- **Radiation background:**

  Photon "gas" generated via n-γ processes by hadrons interacting in the absorber

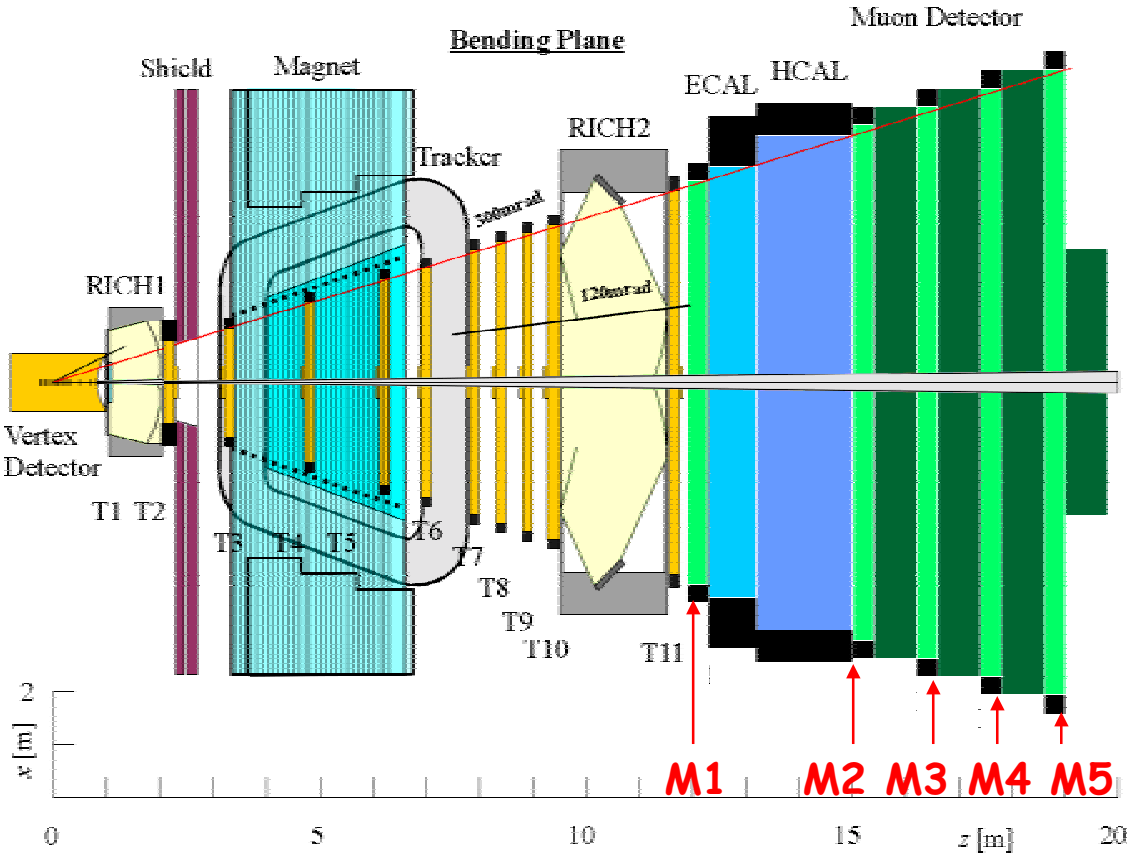
- **Machine background:**

  Energetic muons produced in beam-gas interactions and in machine elements upstream of the experimental area

Requirements:

- High rate capability of chambers and good ageing properties of detector components
- System layout of sufficient granularity to provide a redundant muon trigger.

Overview

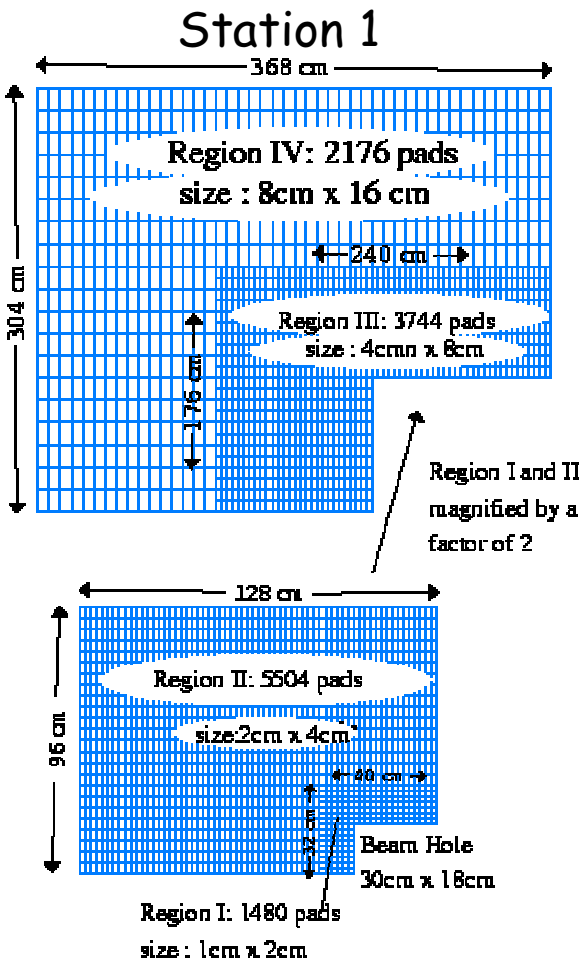


- 5 Muon stations with 2 layers/station
- 870m^2 of detector area arranged in ~1500 chambers
- Hadron Absorber of 21 λ thickness

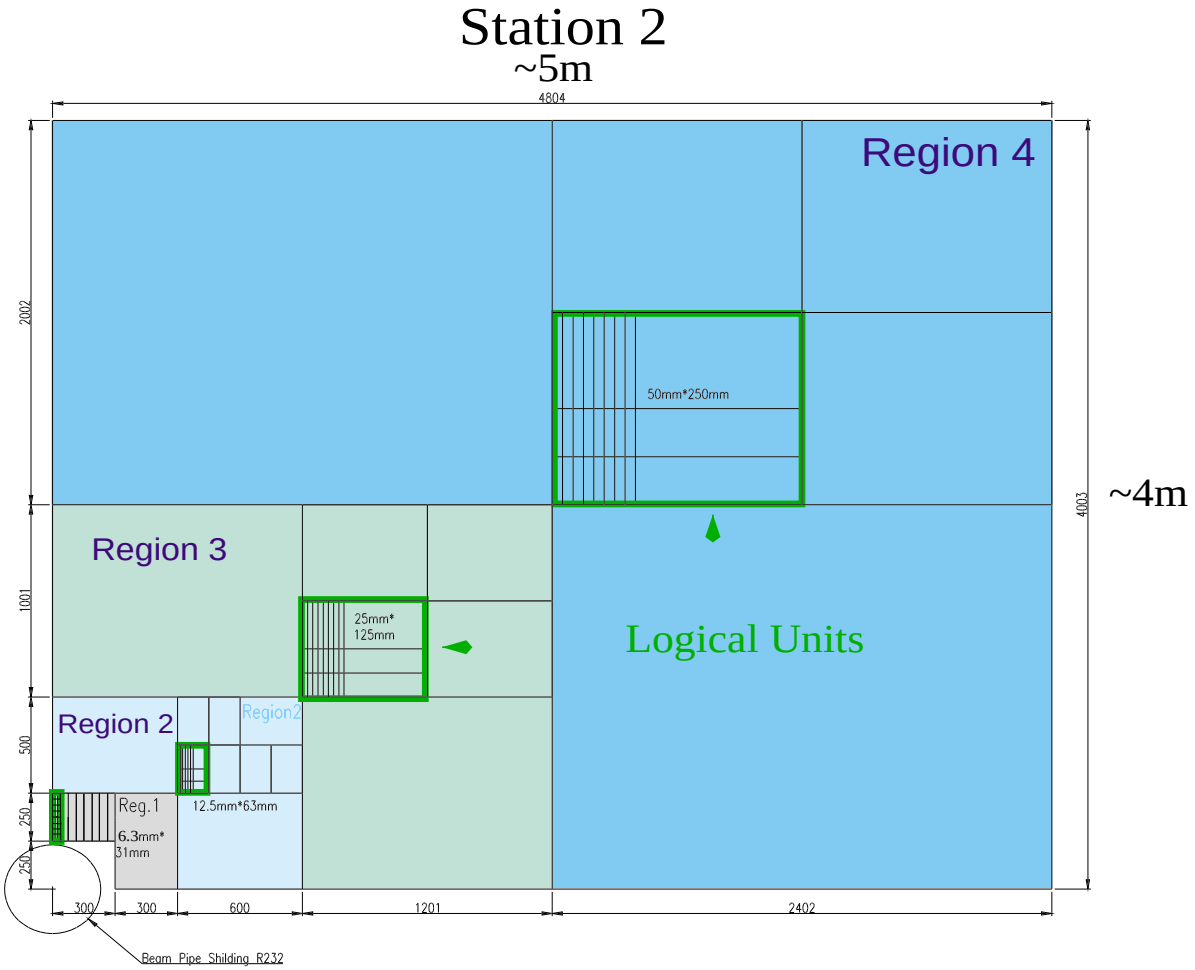
- Stations M1 and M2 are used for the P_T-measurement
- Stations M2, M3 (trigger seed), M4 and M5 for muon track finding

Muon Detector Layout

TP-Layout



Optimized Layout



Muon Detector Layout

Optimized Layout:

- Stations are subdivided in 4 regions with different pad size
  -> Region- and Pad-sizes scale by factor 2
- Pad dimensions scale with station number
  -> Projectivity to interaction point
- Physical pads in stations M2-M5 are grouped to logical strips
- Due to the high occupancy in M1 strips are not possible.
  -> Significant reduction of channel number:

  Total number of physical channels: ~150 k (TP: ~240k)
  Total number of logical channels: ~ 26k (TP: ~45k)
- Required resolution in the bending plane leads to an x/y aspect ratio of 1/4 in stations M2 and M3 and 1/2 in M1

Particle Rates in the Muon System

Applied Procedure:

- LHCb peak Luminosity of 5×10^{32} cm^2/s has been assumed
- Estimation based on MARS as simulation package
- Safety factor of 2.5 has been applied for M2-M5 and 2 for M1

dN/dA /cm^2/int
Required Rate Capability

	M1	M2	M3	M4	M5
R 1	7.0×10^{-3} 560 kHz	2.5×10^{-4} 100 kHz	2.0×10^{-4} 80 kHz	1.2×10^{-4} 48 kHz	1.2×10^{-4} 48 kHz
R 2	4.0×10^{-3} 320 kHz	1.2×10^{-4} 48 kHz	2.0×10^{-5} 8 kHz	1.0×10^{-5} 4 kHz	8.0×10^{-6} 3.2 kHz
R 3	1.0×10^{-3} 80 kHz	4.0×10^{-5} 16 kHz	4.0×10^{-6} 1.6 kHz	3.0×10^{-6} 1.2 kHz	3.0×10^{-6} 1.2 kHz
R4	3.0×10^{-4} 24 kHz	5.0×10^{-6} 2 kHz	1.0×10^{-6} 400 Hz	7.5×10^{-7} 300 Hz	3.0×10^{-6} 1.2 kHz

Three areas can be distinguished:

I) Rate > 100 KHz II) 100 kHz ≥ Rate > 1Khz III) Rate ≤ 1kHz

Muon System Technologies

Technology Choice:

- In the outer part of M4 and M5 a technology with moderate rate capability can be used -> RPC
  - covers 48% of muon system
- For most of the regions MWPC with anode wire and/or cathode pad readout are the optimal solution
  - covers 52% of the total area
- No technology has been chosen yet for the inner part of station 1
  - integrated charge in 10^8s in a MWPC would be ~ 2-5 C/cm
  - area size corresponds to < 1% of total muon system

	M1	M2	M3	M4	M5
R 1	?	MWPC	MWPC	MWPC	MWPC
R 2	?	MWPC	MWPC	MWPC	MWPC
R 3	MWPC	MWPC	MWPC	RPC	RPC
R 4	MWPC	MWPC	MWPC	RPC	RPC

RPC Detector: Overview

Characteristics:

- Provides excellent timing (time resolution < 2ns)
- Robust and flexible: electrodes and detector are independent
  several configurations possible (single-, double-gap)
- Cheap and simple to construct -> Produced in Industry

Requirements:

- Rate capability: 1.2 kHz/cm^2
  -> Avalanche mode operation with $C_2H_2F_4/C_4H_{10}/SF_6$ 95/4/1 gas mixture
  -> Use low-resistive Bakelite (ρ < 10^{10} Ohm cm)
- Redundant spatial efficiency: > 99% / station
  -> Use two gaps (DRPC or OR-ed SRPC)
- Average cluster size < 1.2 strips (M3) and < 2 strips in M4/M5
- Max. radiation dose (10 y) 100 Gy

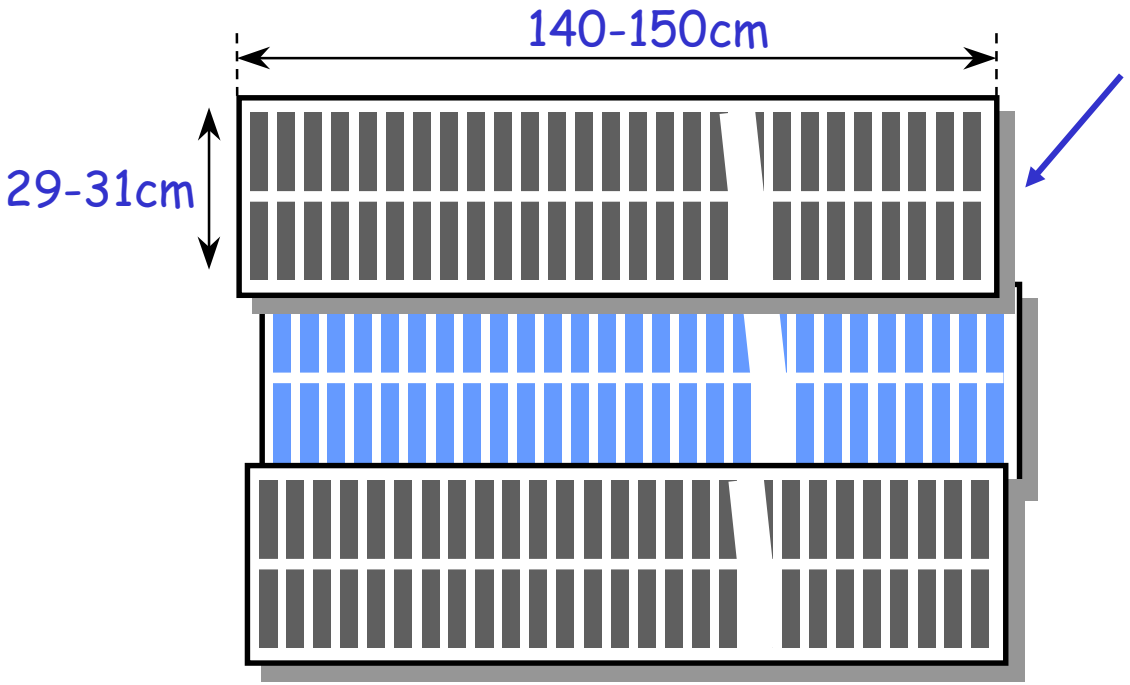
Activities:

Carried out by Firenze and Roma 'Tor Vergata' groups

RPC Detector: Layout

Schematic Layout for Regions 3+4:

- 1 chamber: 2 gas gaps (2 SRPC with independent FE-chips or DRPC)
- Each electrode measures space points (no x-y coincidence required!)



Total region 3 :

- 48 chambers/station
- 4.6k-9.2k FE-ch./station

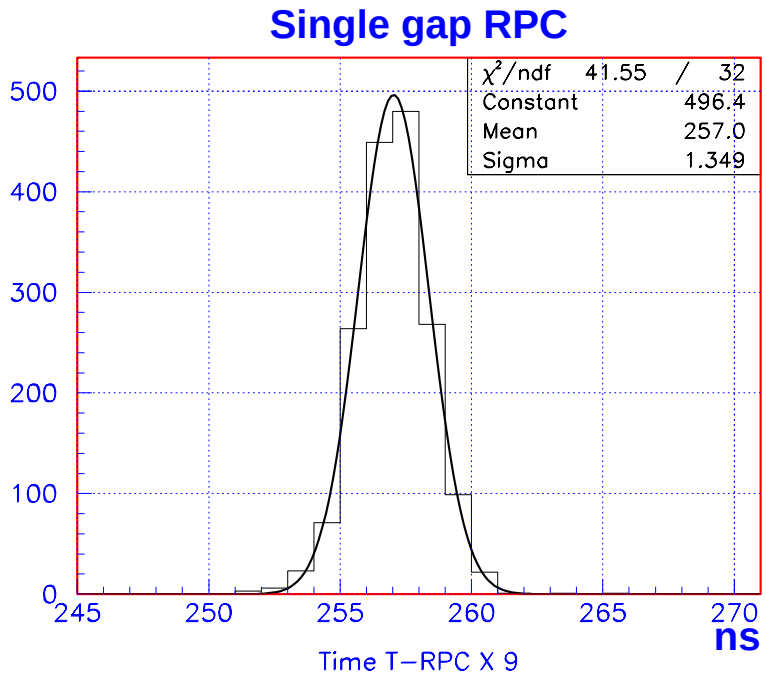
Total region 4 :

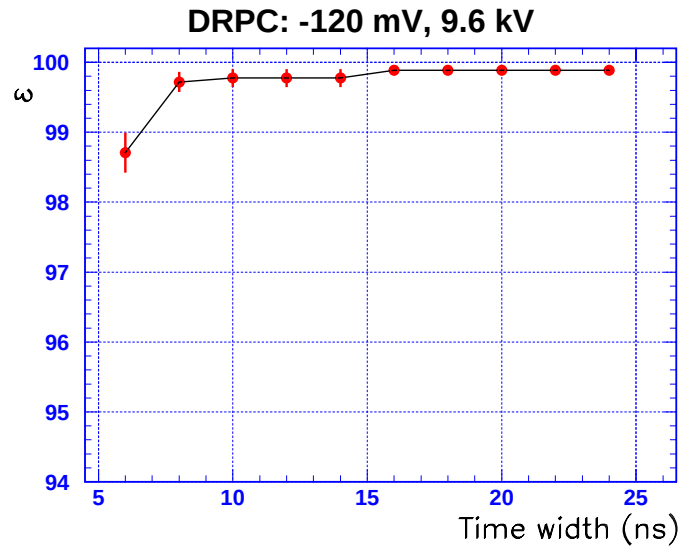
- 96-192 chambers/station
- 9.2k FE-ch./station

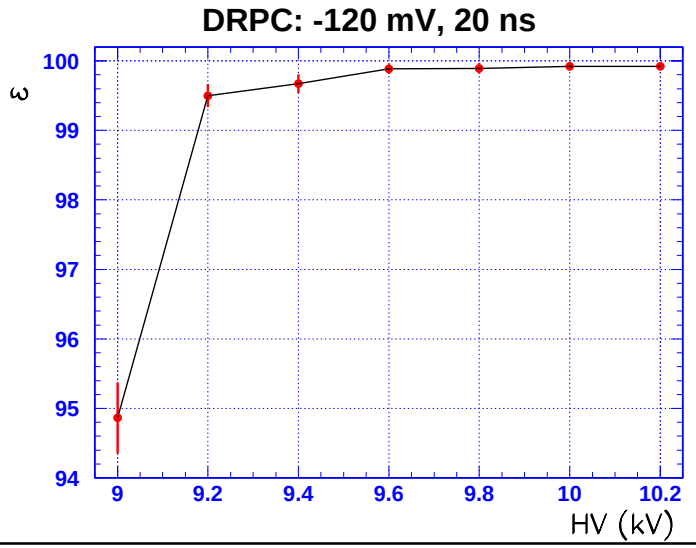
RPC Detector: Performance

Results from tests at the CERN PS:

- Time resolution ~1.3 ns
- Full efficiency within 10 ns time window





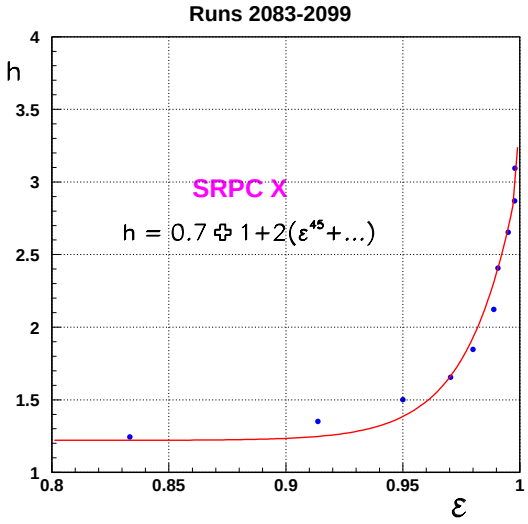


RPC Detector: Cluster Size

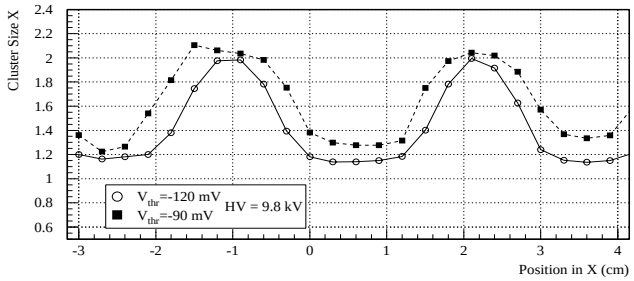
Contributions to the Cluster Size:

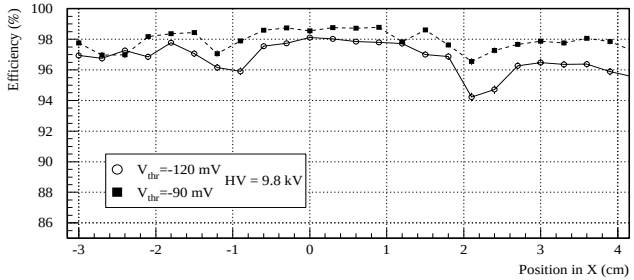
- direct induction
  -> geometrical effect, largest between strips
- cross-talk
  -> depends on electrical characteristics of strip planes

SRPC

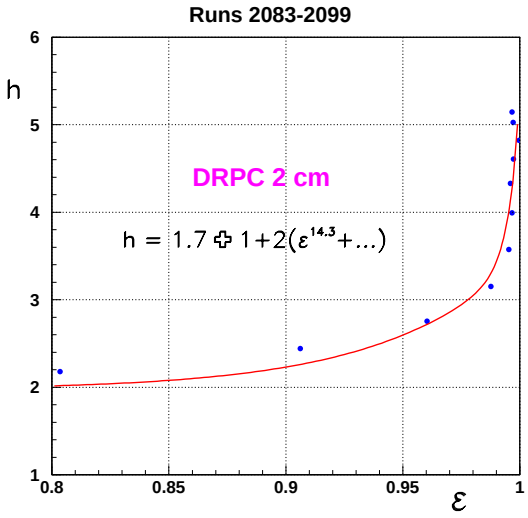


Scan over adjacent strips





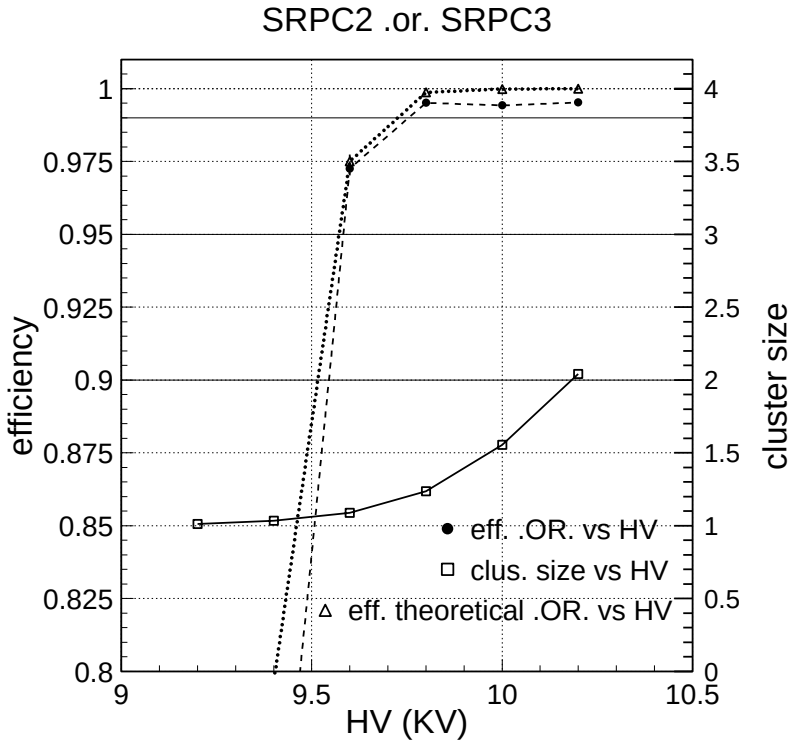
DRPC
(strips less shielded)



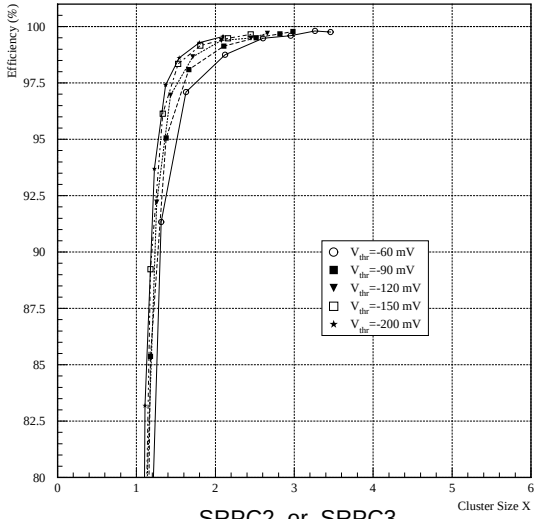
RPC Detector: Performance

Cluster Size Studies:

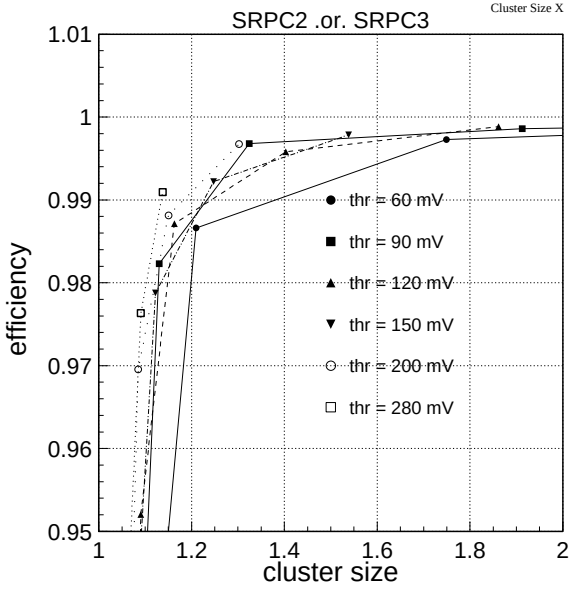
- Cluster size decreases with increasing threshold
- At a given efficiency OR of two SRPC allows lower cluster size



SRPC



Two SRPC in OR



RPC Detector: Rate Capability

Results from GIF-Tests:

- **GIF Photon rate:**

$$R_\gamma = 740\ GBq \times 0.85(BR) \times 0.5/Att. \times 1/4\pi r^2 \times \varepsilon_\gamma$$

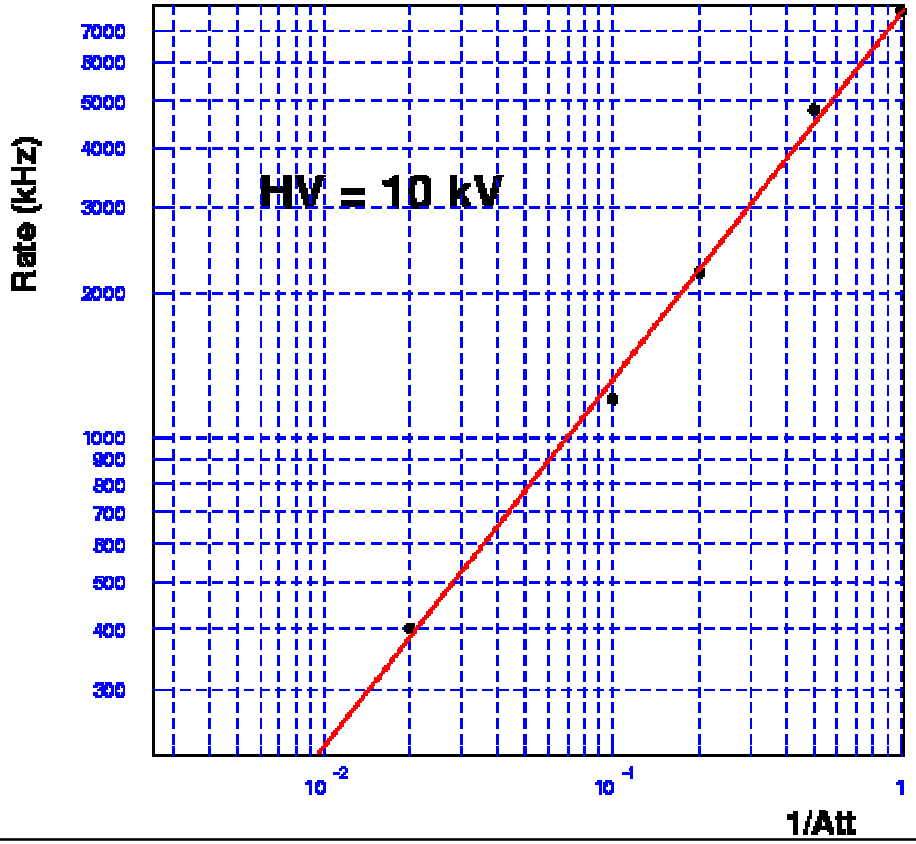
- **Procedure:**

Determine R_γ from measured plateau curve with photons

$$R_\gamma = 3.1\ (1/Att)^{0.76}\ kHz/cm^2$$

Calculate photon sensitivity factor

$$\Rightarrow \varepsilon_\gamma \sim 1/800$$



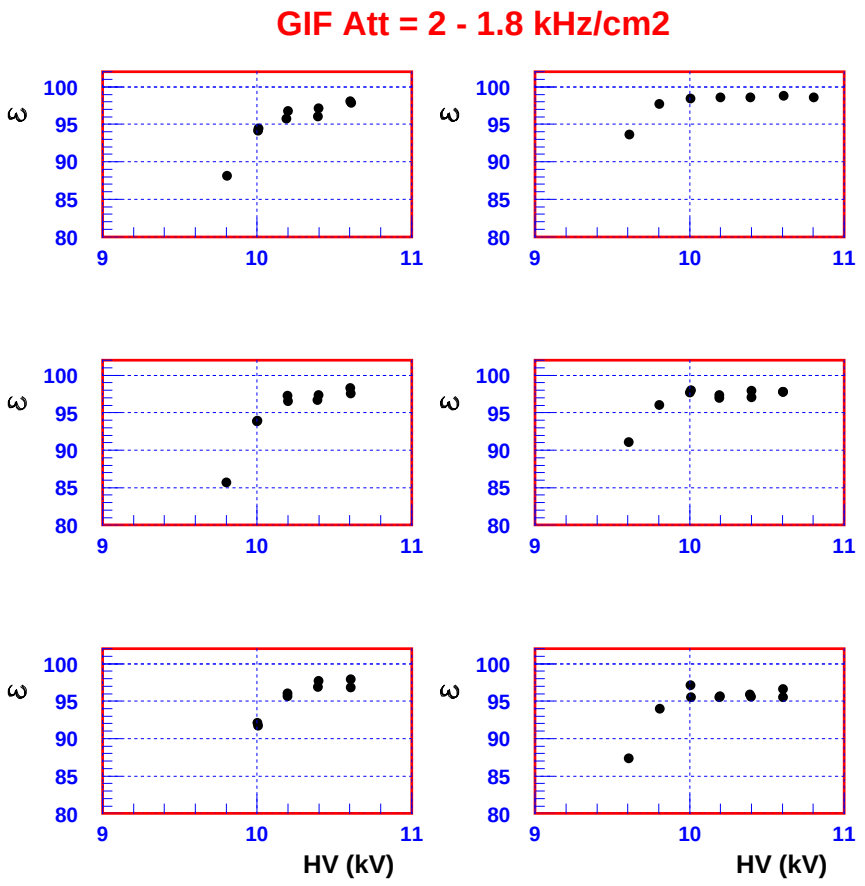
RPC Detector: Rate Capability

Results from tests at GIF:

- Gamma Irradiation Facility allows to test muon chambers under conditions comparable to those expected at the LHC.
- Test of 3 SRPC with x and y planes

-> Efficiencies of >95% have been obtained at 1.8 KHz/cm^2

-> RPC of low resistive material show good rate capability behavior



x-planes y-planes

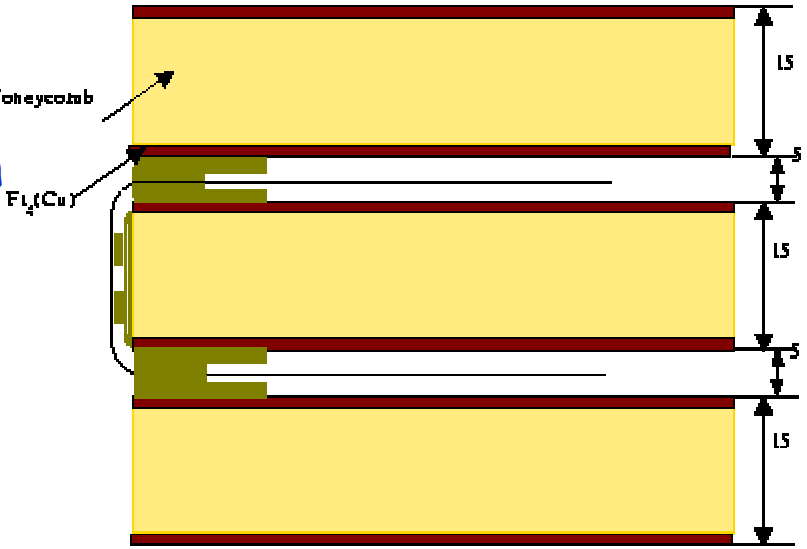
MWPC Detector: Overview

Characteristics:

- MWPC with anode and/or cathode readout are very well known
- Integrated charge in 10 LHC years (10^8s) is **<1 C/cm** in all regions considered
- MWPC operated with $Ar/CO_2/CF_4$ 40/50/10 mixture has good aging properties

Requirements:

- Efficiency within 20 ns time window: > 95%
  -> Two gaps, staggered, 1.5mm wire spacing
- Redundant spatial efficiency: > 99% /station
  -> Two independent double gap chambers



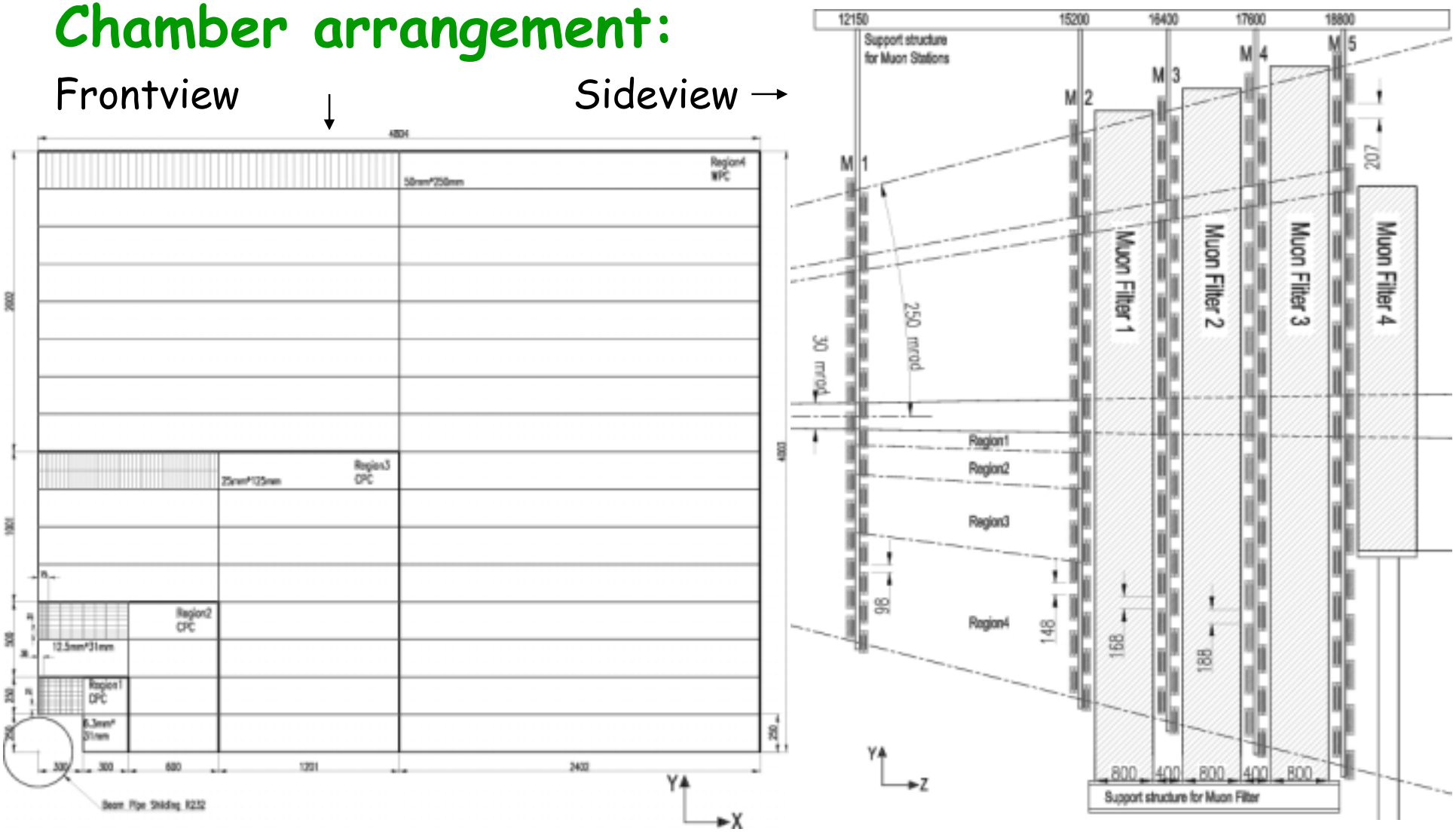
Activities:

Carried out by PNPI (proponent), CERN, Firenze, Ferrara, Roma I (Potenza) and UFRJ groups

Muon Detector Layout

Chamber arrangement:

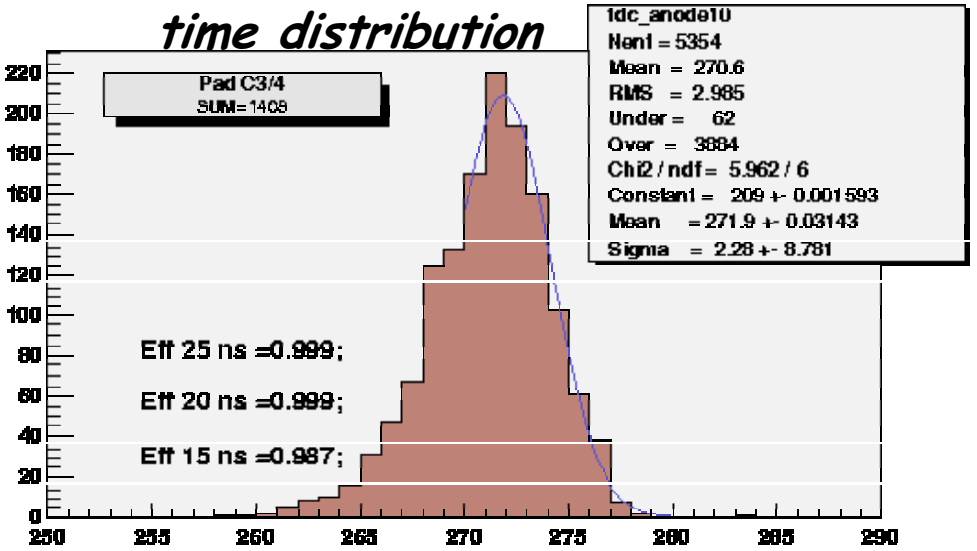
Frontview ↓ Sideview →

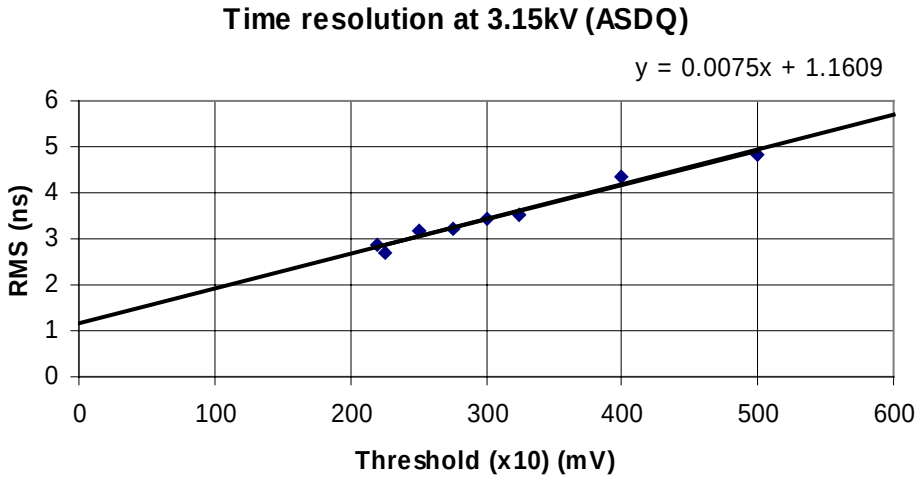


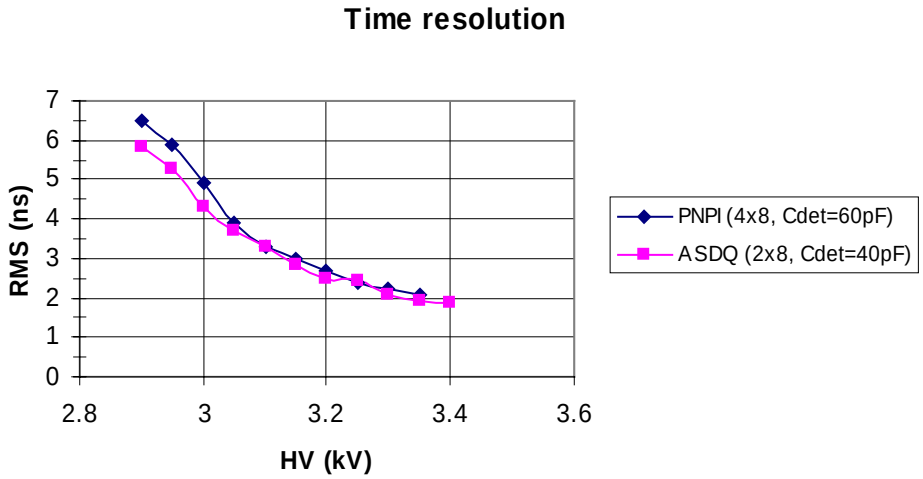
MWPC : Performance

Timing Properties:

Time resolution <3ns
at operating point







MWPC: Performance

MWPC test at CERN PS:

Gas Mixture:

$Ar/CO_2/CF_4$ 40/50/10

FE-electronics:

Custom made (SMD)

peaking time ~10ns

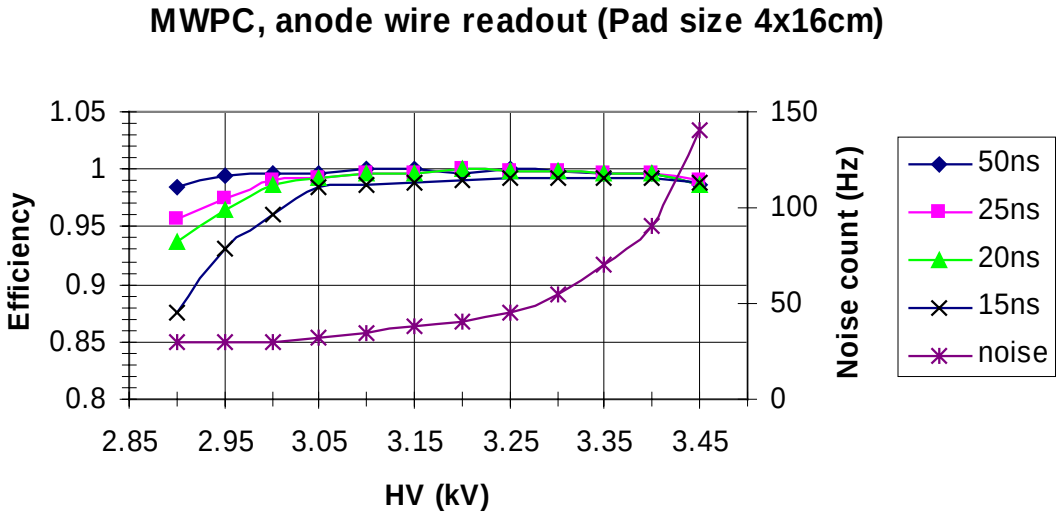
-> Efficiency >99% within 20ns time window

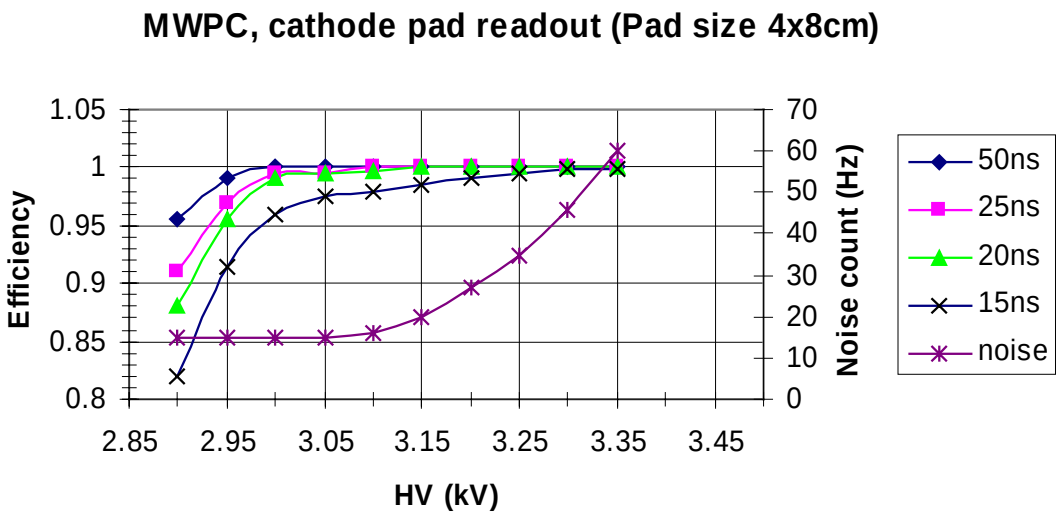
-> Dark count rate below < 50Hz/pad

-> plateau length:

~ 400V for WPC

~ 300V for CPC

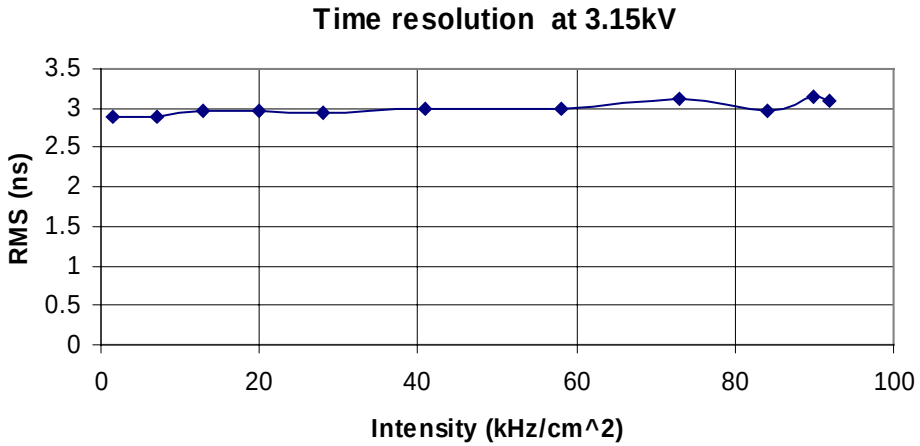


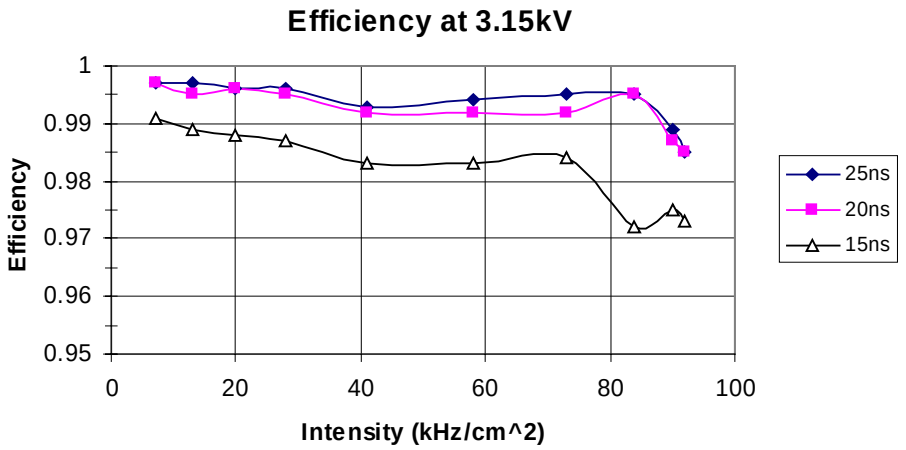


MWPC: Performance

High rate performance:

- FE-chip: ASDQ (has baseline restoration)





-> Efficiency > 98% within 20ns time window

-> No deterioration of timing properties

FE - Electronics

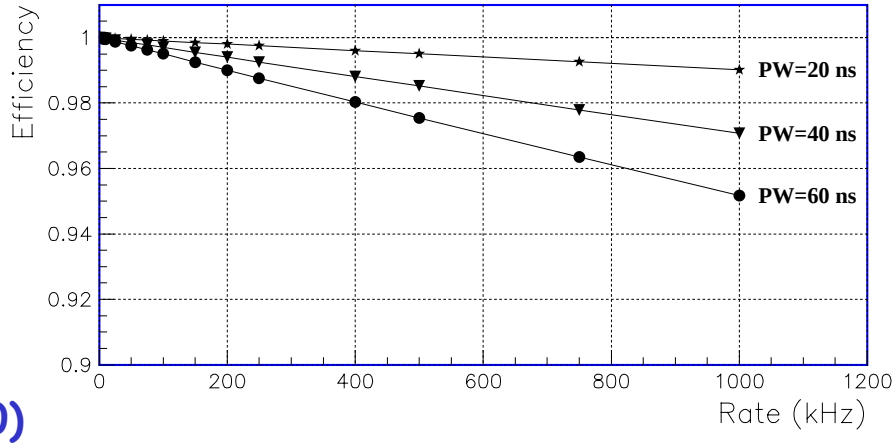
FE-chip specifications:

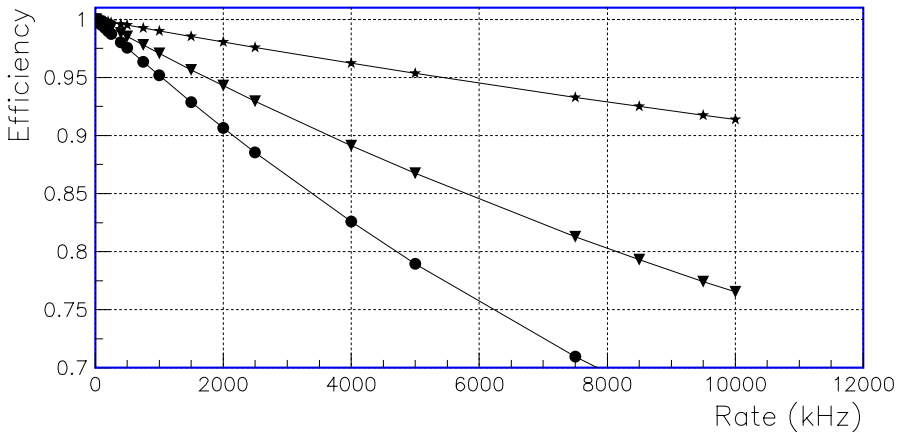
- Peaking time ~10ns
- R_{in}: < 50 Ω
- C_{det}: 10-250pF
- Polarities: +/-
- Rate: up to 1MHz
- Dead time: < 50ns
- Dose: up to 1Mrad
- Sensitivity: ~10mV/fC (@C_{det} =0)
- Low noise . . .

(Less stringent requirements for RPC FE-chip)

-> Try to find existing chip satisfying our requirements

Inefficiency due to ASD pulse-width





FE - Electronics

FE-chip candidates:

MWPC:

- PNPI SMD (only for prototype studies)
- SONY ASD (Tested, radiation limit ~ 50krad, dead time ~90ns)
- ASDQ (R_{in} = 280Ω, requires slight modification.)
  -> Performs in general very well
- MINSK ASD (matches well specifications, to be tested)
- CMP 16 (for anode readout of CMS-EMU-chambers, to be tested)
- GaAs (to be tested)
- CARIOCA (0.25 μ CMOS) (under development)

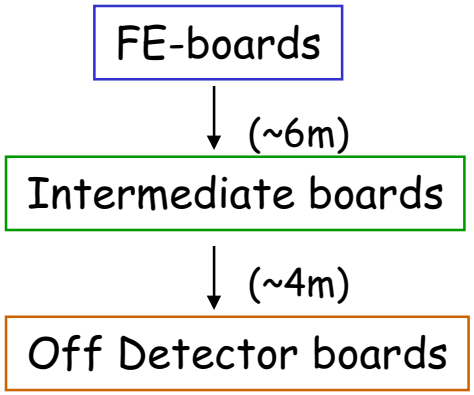
RPC:

- GaAs (0.6 μ MFET) (ATLAS RPC chip, very fast, radiation hard)
  -> Baseline option
- Bari (0.8 μ BiCMOS) (CMS RPC chip)

FE-Architecture

Status:

- Basic concept of the FE-Architecture has been developed
- Data reduction from physical channels (~150k) to logical channels (~26k) done in intermediate boards
- Synchronization of data from the various stations (timing alignment of signals) with muons using a 3-bit TDC



-> (ASD-chip) -> digital signals

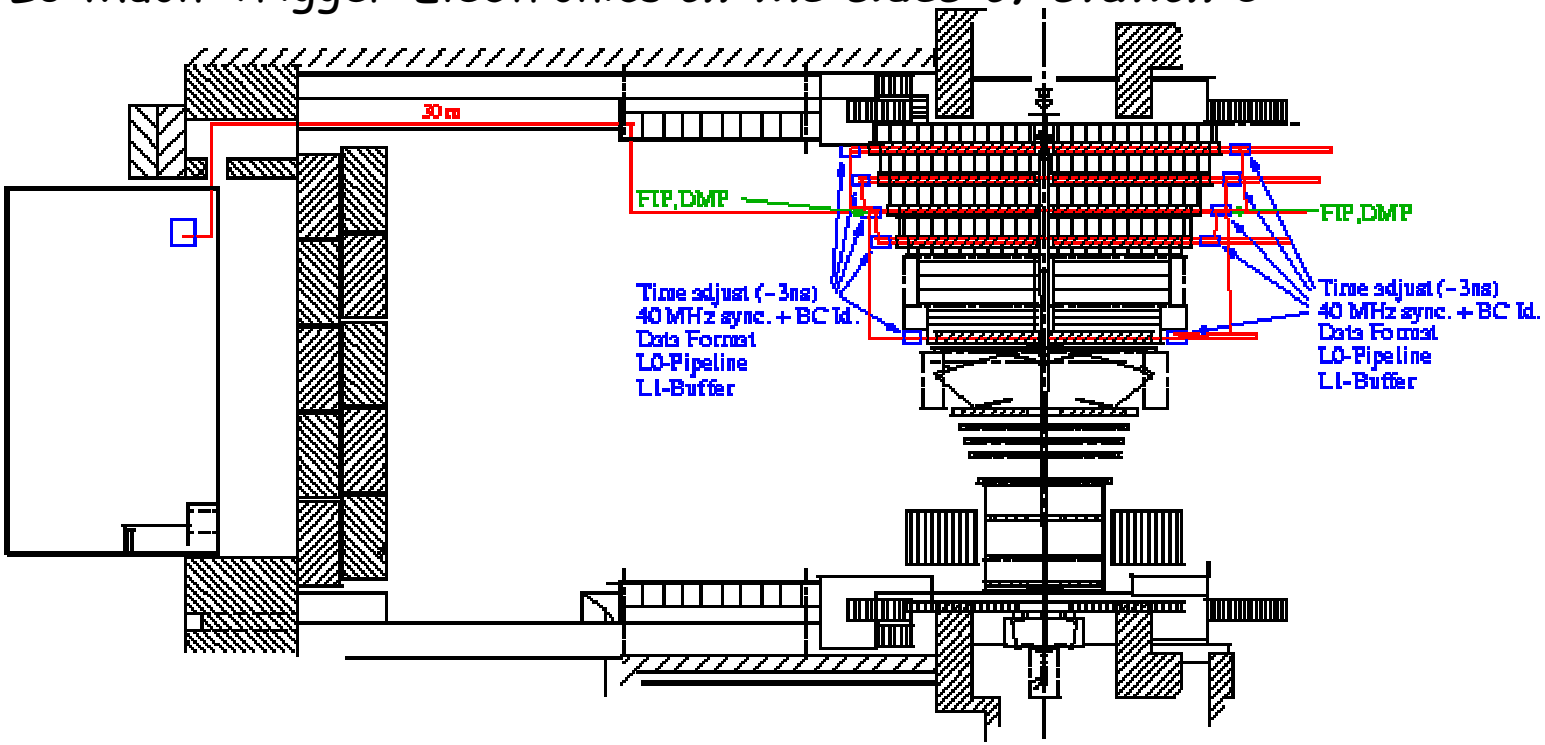
-> channel reduction, FE-control

-> Synchronization, Pipelines, Trigger interface

FE-Electronics Locations

Baseline Locations for FE-Electronics:

- FE-boards with kind of ASD chip ***on the chambers***
- Intermediate boards ***on the sides of each station***
- Off detector Boards performing synchronization, Data Format+BC Id, LO-Pipeline and L1-Buffer ***on the sides of each station***
- LO-Muon-Trigger-Electronics ***on the sides of station 3***



Project Plan

Schedule:

• Decision on optimized muon detector layout	Jan. 2000
• Choice of detector technologies	Feb/May 2000
• Finalization of chamber design	End 2000
• Baseline choice of FE-chip	End 2000
• Technical Design Report (TDR)	Early 2001
• Preparation of Production lines	2001
• Construction and test of muon chambers	2002-2003
• Installation and commissioning of the muon system	2004

Conclusions

Layout and Architecture:

- Optimized layout has been found, requiring less physical and logical channels
- Realistic data flow between chambers and the Trigger/DAQ System

Detector Technologies:

- **RPC:** - Rate capability of ~ 3 kHz/cm^2 has been obtained
  - Time resolution of 1.3 ns with efficiency >99% in 10 ns time window
- **MWPC:** - Chambers perform very well up to rates > 100 kHz/cm^2
  - Time resolution < 3 ns with efficiency > 99% in 20 ns time window
  - Good ageing properties for $Ar/CO_2/CF_4$ (local tests > 13C/cm)

Muon System is proceeding well towards the Technical Design Report