LHCb Muon System TDR

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- Overview of the Muon System
- Physics Performance
  - L0 muon trigger
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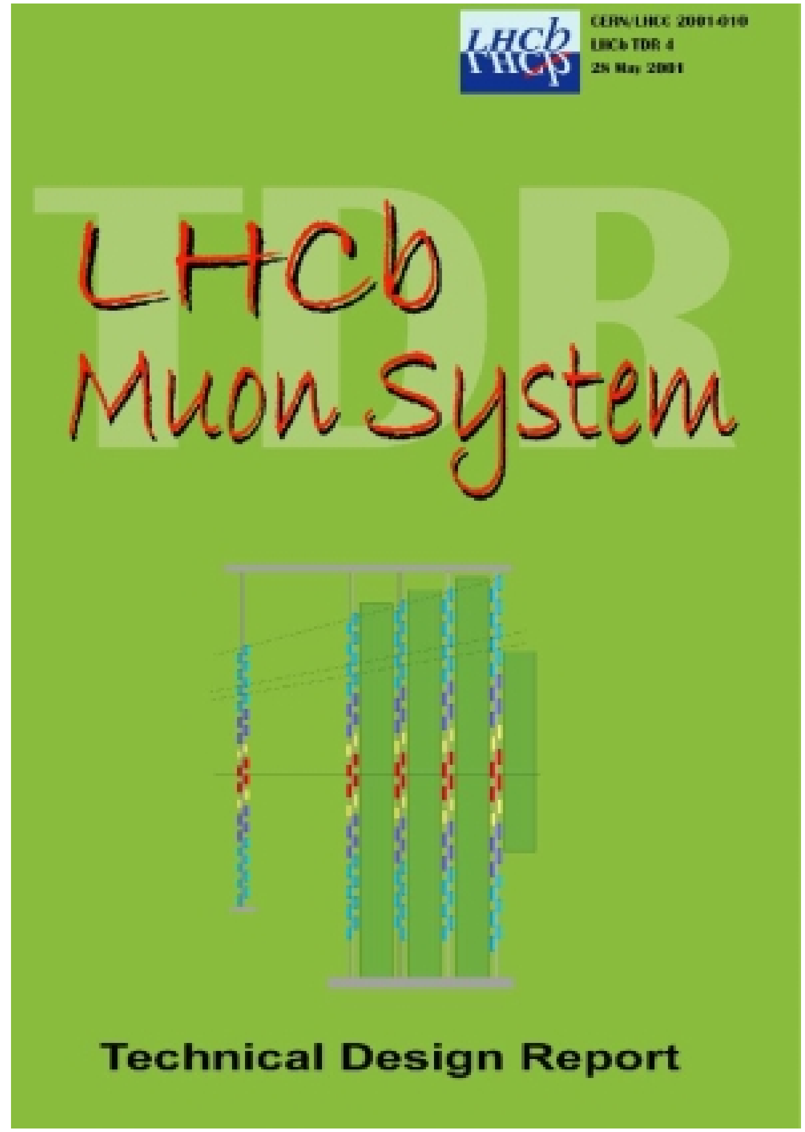
  - Detector design and construction
  - FE-chip and chamber prototype studies
- RPC Detector
  - Prototype studies
  - Detector design and construction
- Readout Electronics
- Project Organization



G.Carboni and B.Schmidt on behalf of the LHCb Muon Group

Introduction

Physics Goals:

- The Muon system of *LHCb* is primarily used to trigger on muons produced in the decay of b-hadrons: $b \rightarrow \mu X$;
  In particular: $B^0 \rightarrow J/\psi(\mu^+\mu^-)\, K_s$; $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\, \Phi$; $B_s^0 \rightarrow \mu^+\mu^-$

- The muon momentum is measured precisely in the tracking system
- The muon system identifies muons from tracks in the tracking system

Requirements:

- Modest momentum resolution (~20%) for a robust P_T -selective trigger
- Good time resolution (a few ns) for reliable bunch-crossing identification
- Good muon identification (~90%); small pion-misidentification (~1%)

Introduction

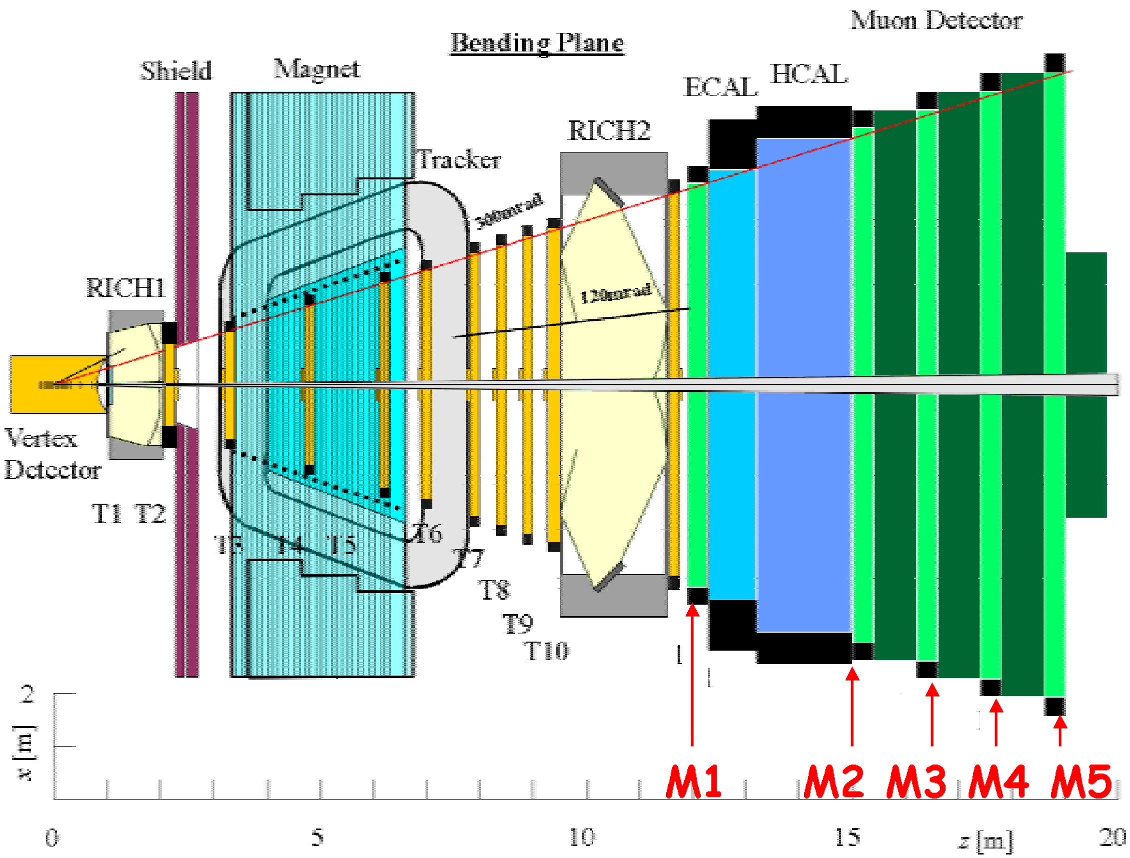
Background sources in the LHC environment:

- **π,K $\rightarrow$ μ X decays**
  - main background for L0 muon trigger
- **Shower particles**
  - hadron punch-through including shower muons
- **Low-energy background induced by n-γ processes**
  - contributes significant to chamber hit rate
- **Machine background, in particular high energy beam-halo muons**

Requirements:

- High rate capability of chambers
- Good ageing properties of detector components
- Detector instrumentation with sufficient redundancy

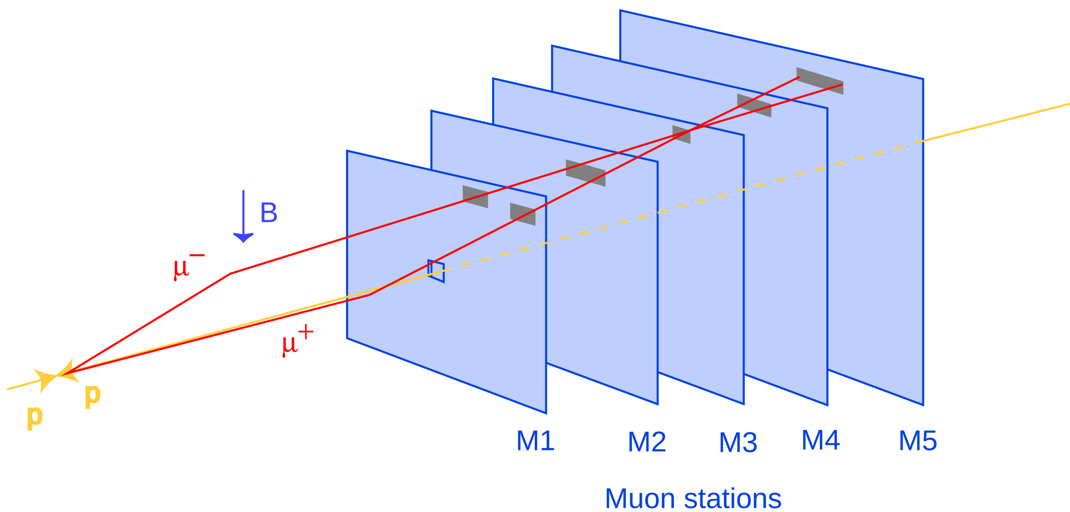
Overview

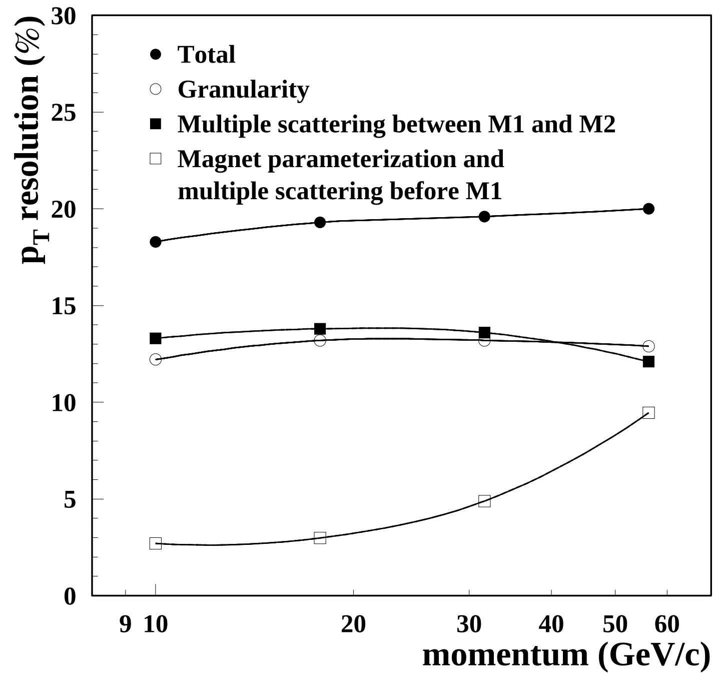


- 5 Muon stations with 2 independent layers/station
  - redundancy
- Layers are logically ORed
  - high station efficiency
- 435m^2 of detector area with 1380 chambers
- Hadron Absorber of 20 λ thickness

Muon Trigger Algorithm

Level 0 Muon Trigger:





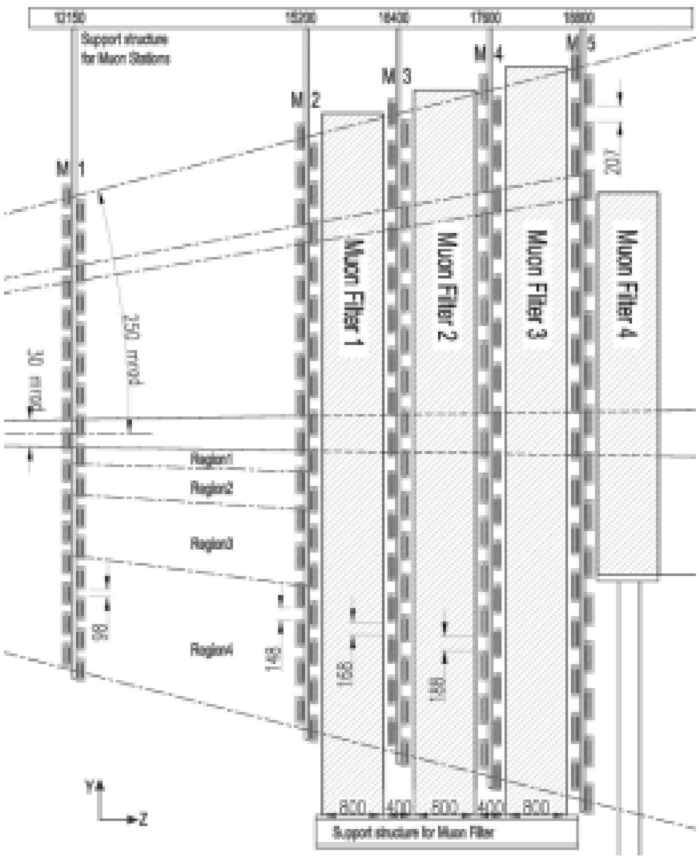
Muon track finding:

- Find seed pad in station M3
- Find pads within opened search windows (FOI) in stations M2, M4 and M5
- Use pads found in M2 and M3 to extrapolate to M1 and find pad in M1 within FOI
- Stations M1 and M2 are used for the P_T-measurement

  -> Muon Trigger exploits multiple scattering in the muon shield by applying tight search windows

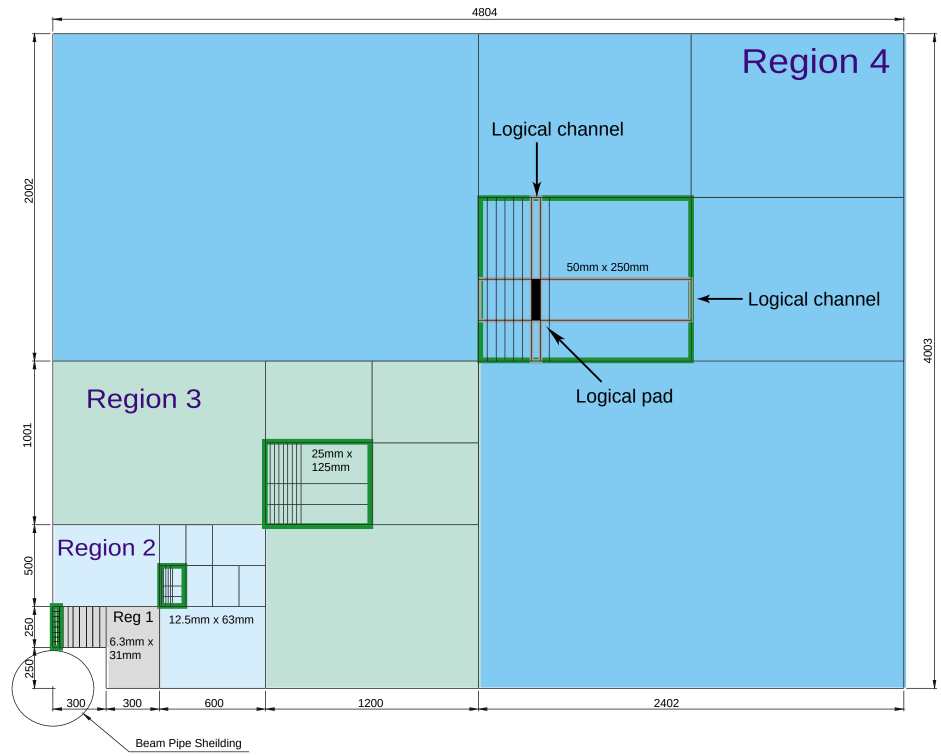
Muon Detector Layout

Side view:



Front view:

(1 Quadrant of Station 2)



-> Projectivity to interaction point

Total number of physical channels: ~120 k (TP: ~240k)
Total number of logical channels: ~ 26k (TP: ~45k)

Particle Rates and System Technologies

Procedure to determine particle rates:

- LHCb peak Luminosity of 5×10^{32} cm^2/s has been assumed
- Safety factor of 5 has been applied for M2-M5 and 2 for M1

Required Rate Capability per cm^2
Technology Choice

	M1	M2	M3	M4	M5
R 1	460 kHz t.b.d.	37.5 kHz MWPC	10 kHz MWPC	6.5 kHz MWPC	4.4 kHz MWPC
R 2	186 kHz t.b.d.	26.5 kHz MWPC	3.3 kHz MWPC	2.2 kHz MWPC	1.8 kHz MWPC
R 3	80 kHz MWPC	6.5 kHz MWPC	1.0 kHz MWPC	750 Hz RPC	650 Hz RPC
R4	25 kHz MWPC	1.2 kHz MWPC	415 Hz MWPC	250 Hz RPC	225 Hz RPC

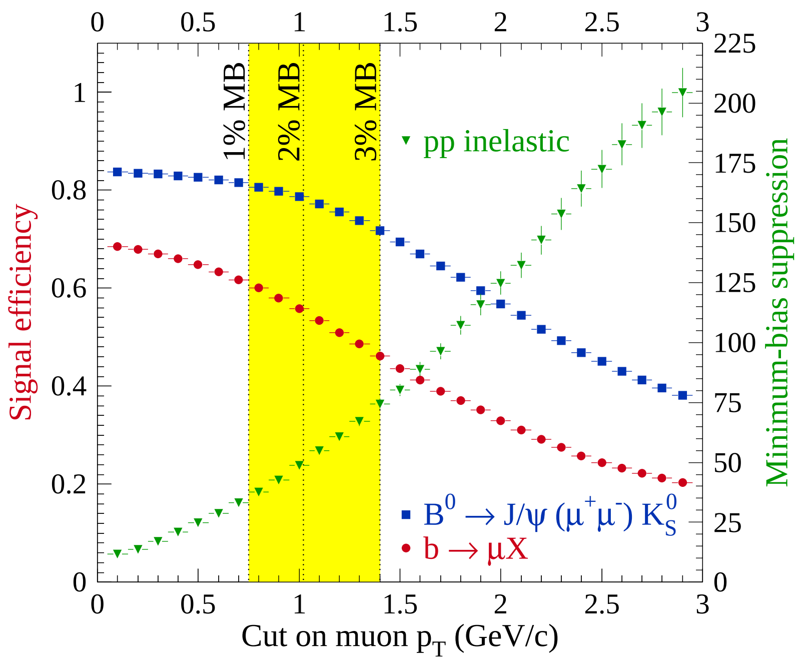
Technology Choice:

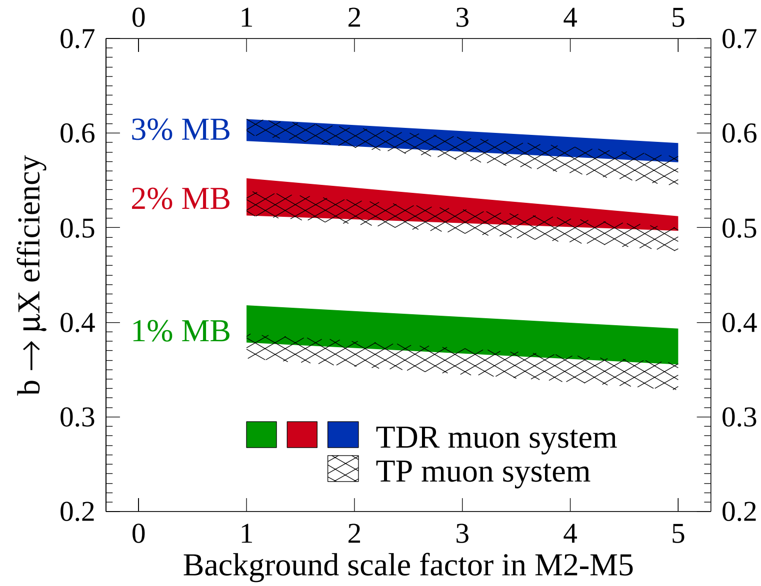
- In the outer part of M4 and M5 a technology with a rate capability of $1kHz/cm^2$ and cross talk of 20-50% can be used -> RPC, covers 48% of muon system
- For most of the regions MWPCs with a time resolution about 3ns are the optimal solution. -> MWPC, cover 52% of the total area
- No technology chosen yet for the inner part of M1 (<1% of total area). Technologies under consideration: triple GEMs and asymmetric wire chambers

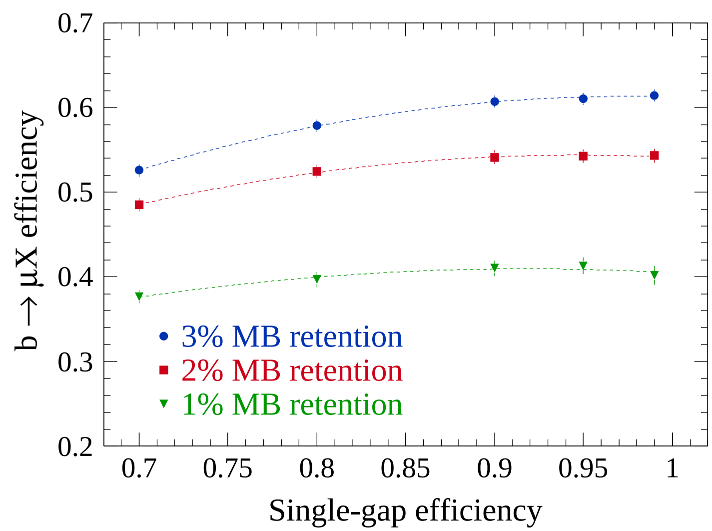
Level 0 Muon Trigger

Trigger Performance:

- TDR Muon system includes realistic chamber geometry and detector response







-> **TDR Muon System is robust**

-> Slight improvement in performance compared to the TP Muon System.

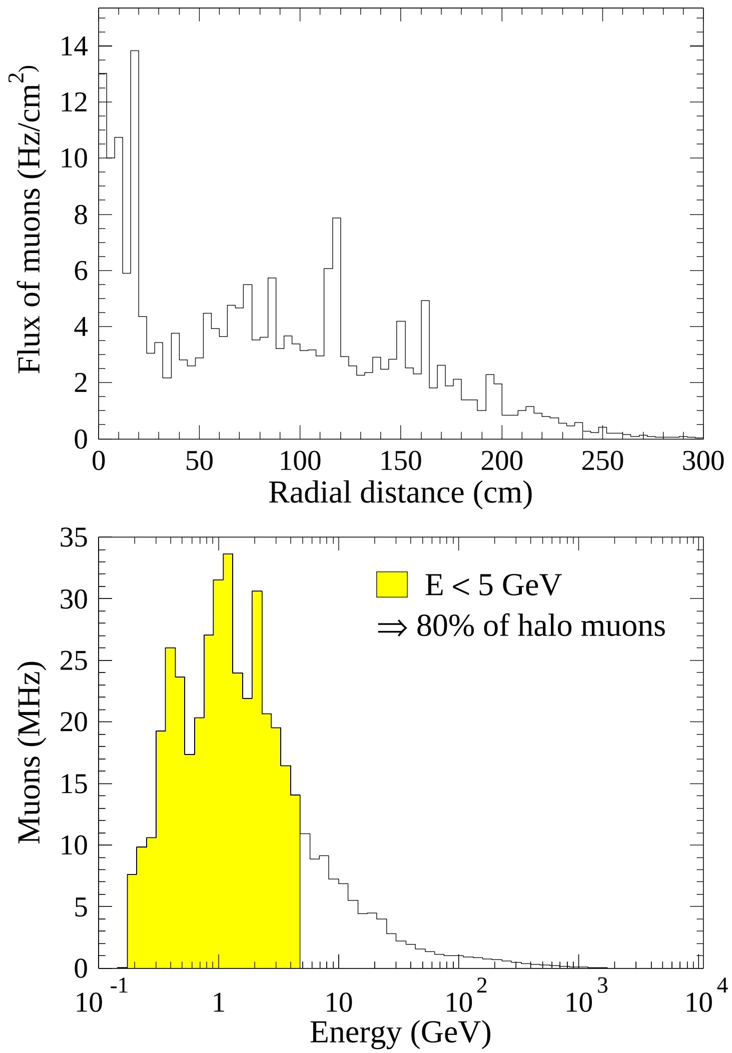
Level 0 Muon Trigger

Beam halo muons:

- Distribution of energy and radial position of halo muons 1m upstream of IP travelling in the direction of the muon system →
- Muons entering the experimental hall behind M5 give hits in different BX in the muon stations

-> No significant effect

- Halo muons are present in ~1.5% of the bunch crossings
- About 0.1% of them cause a L0 muon trigger

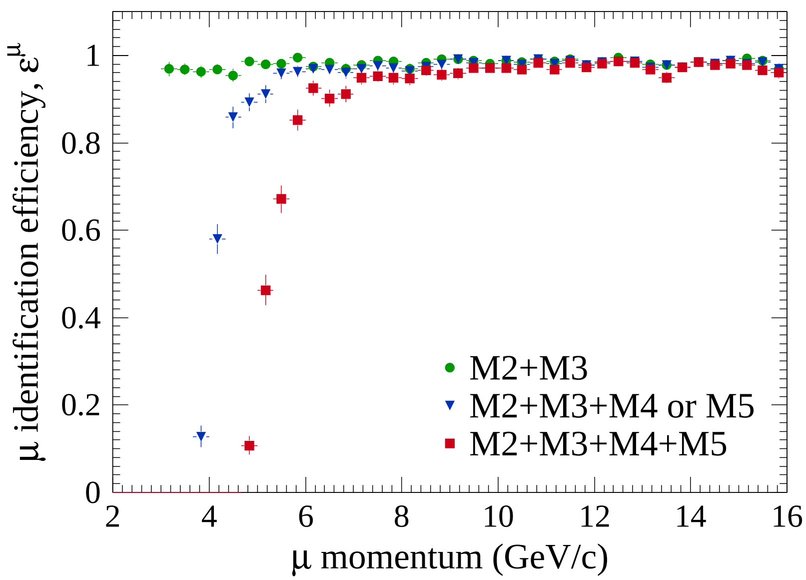


Muon Identification

Algorithm:

- Extrapolate reconstructed tracks with p > 3GeV/c and first hits in Velo from T10 to the muon system (M2 etc.)
- Define a field of interest (FOI) around extrapolation point and
- Define minimum number of stations with hits in FOIs

- M2+M3 for 3 < p < 6 GeV/c
- M2+M3+(M4 or M5) for 6 < p < 10 GeV/c
- M2+M3+M4+M5 for p > 10 GeV/c



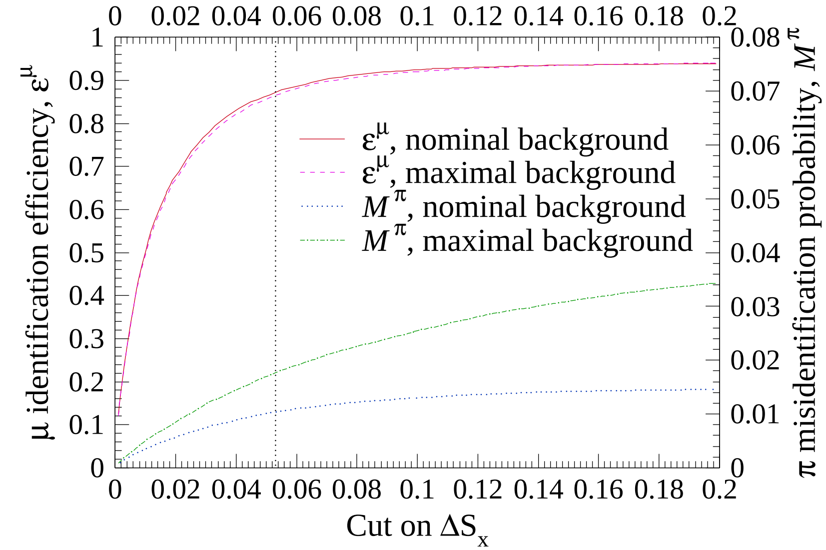
Muon Identification

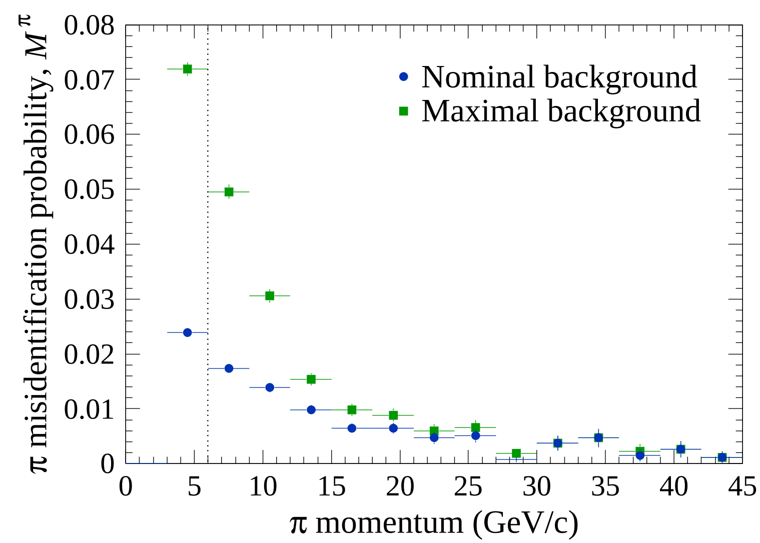
Performance:

	Nominal background	Maximal background	
			p>6GeV/c ΔSx<0.053
ε^{μ}	94.0±0.3	94.3±0.3	90.0±0.6
M^{e}	0.78±0.09	3.5±0.2	0.6±0.1
M^{π}	1.50±0.03	4.00±0.05	1.2±0.05
M^{K}	1.65±0.09	3.8±0.1	1.2±0.1
M^{P}	0.36±0.05	2.3±0.1	0.3±0.1

Additional cuts on slope difference ΔSx between tracking and muon system and p^{π} are required in case of large bkg.

-> M^{π} ~ 1% ε^{μ} ~ 90%



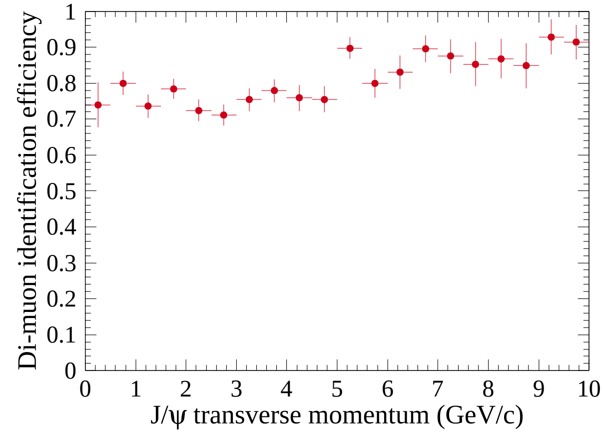


Muonic Final States

$B^0 \to J/\psi(\mu^+\mu^-)\ K_s$:

- Well established CP-violating decay from which angle β in the unitary triangle can be determined.
- $J/\psi\ (\mu^+\mu^-)$ reconstruction:
  - oppositely charged tracks identified as muons.
  - Mass of dimuon pair consistent with J/ψ mass

  -> More than 100k ev./year expected in LHCb

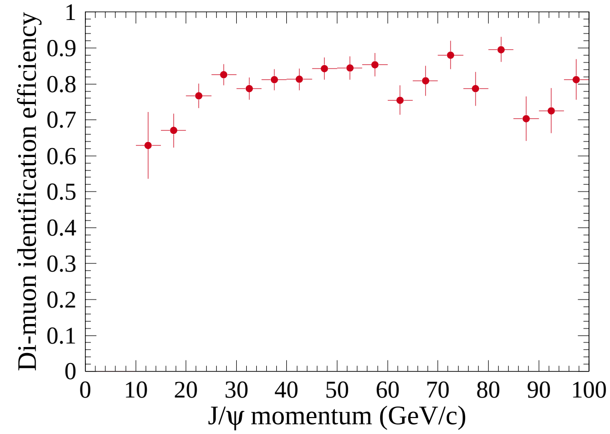


$B_s^0 \to \mu^+\mu^-$:

- Decay involves FCNC and is strongly suppressed in the Standard Model

  -> B^0 mass resolution 18 MeV/c^2

  -> ~10 signal events over 3 bkg expected per year



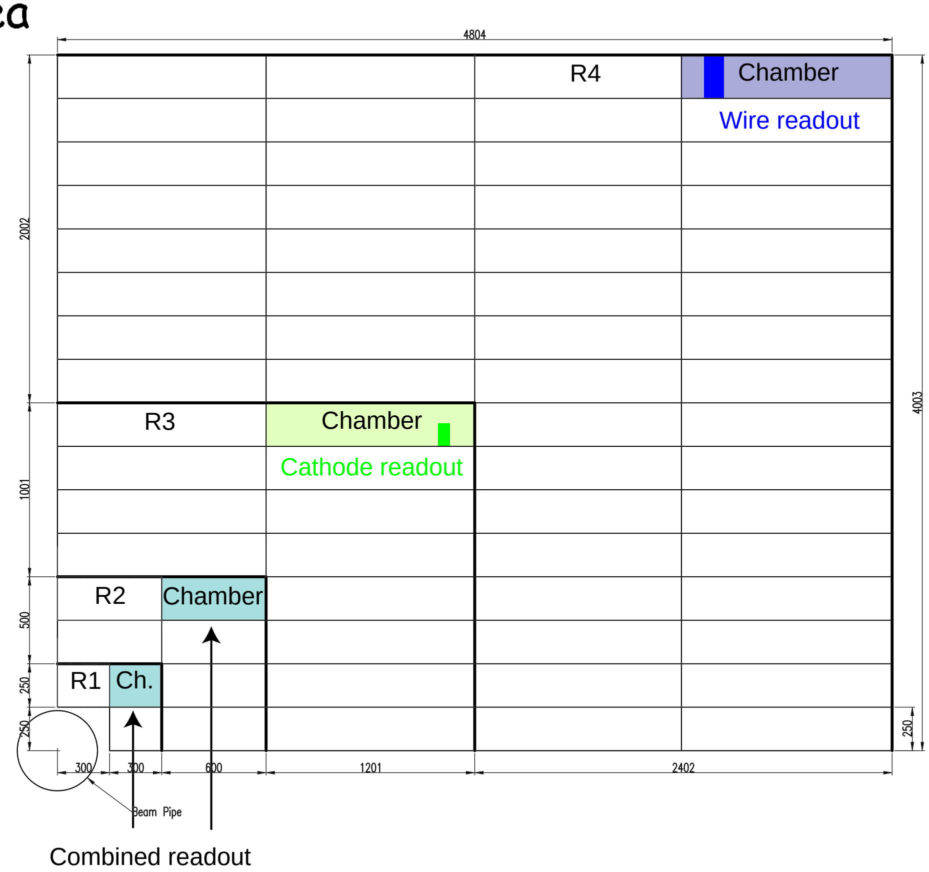
L0 performance for both decays:

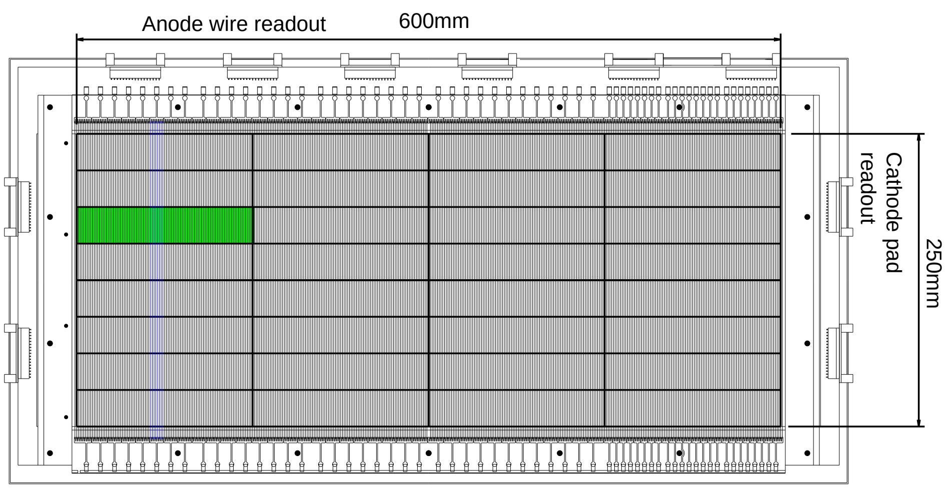
- L0 trigger acceptance of fully reconstructed events is 98%.
- L0 muon acceptance is 95% with >70% triggered by muon trigger alone.

MWPC Detector : Overview

Overview:

- MWPC detector covers 52% of total area
- 864 chambers (up to 276/station)
- Same chamber height in all regions of a station (M1: 30cm ; M5: 40cm)
- Chamber length varies from 40-140cm
- Chambers have Anode and/or Cathode readout with ~80k FE-channels in total





Example of chamber for Region 2

MWPC Detector

Performance requirements:

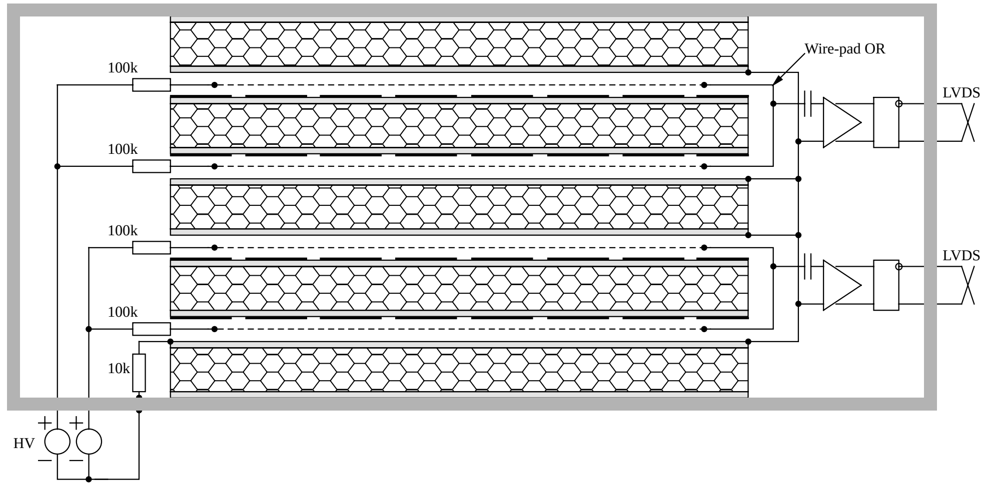
- Efficiency within 20ns time window >99% :

  -> 1.5mm wire spacing

  -> Hardwired OR of two 5mm gaps per FE-channel

- Redundancy:

  -> Two independent double gaps



- Good ageing properties: -> Gas mixture: $Ar/CO_2/CF_4$ 40:50:10

  -> Charge densities in 10 LHCb years: -> 0.5 C/cm on wires and 1.7 C/cm^2 on cathodes

  -> Ageing test is continues in GIF: -> up to now about 30% of total charge accumulated, no important effect

Chamber Components

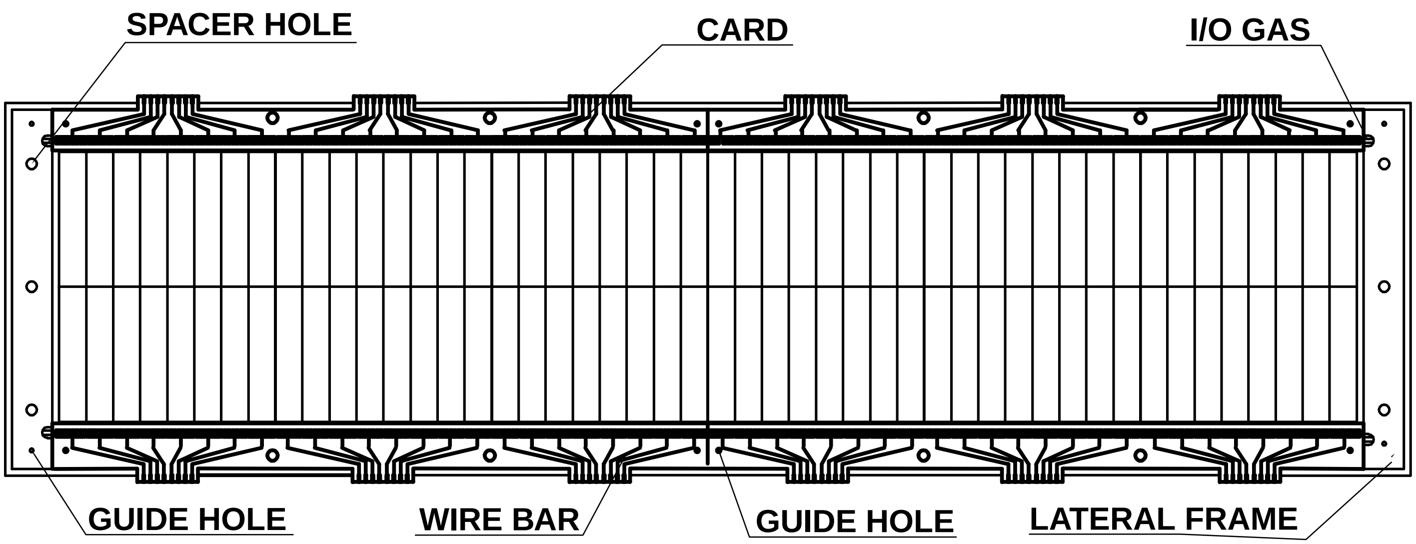
Panels:

- Key element in MWPC, ±50µm precision over 40cm x 140cm required
  - Nomex Honeycomb panels are baseline choice (made good experience in tests)
  - Other materials like polyurethanic foam are under consideration

Cathode PCB:

- For Region 3 access to cathode pads from top and bottom,
- For Region 1 and 2, double layer PCB with readout traces

Capacitance between cathode pads ~ 4 pF. -> Electrical cross talk ~2%



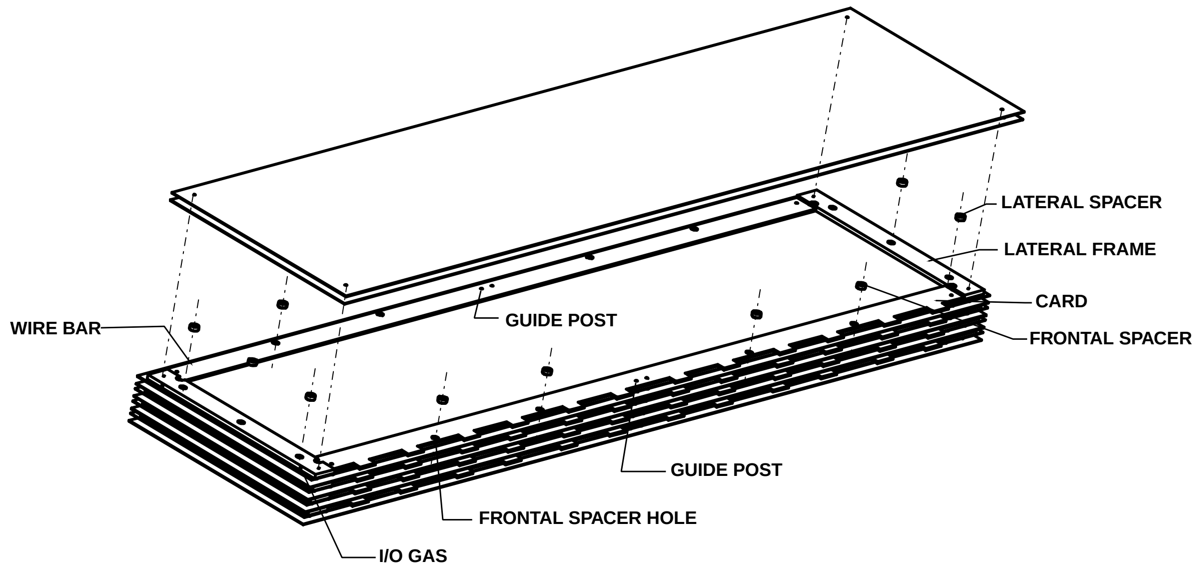
Chamber Components

Frames:

- Solution which does not require precision on wire fixation bars has advantages
  -> Precision could come from spacers introduced every 10-15cm in the frames
- Side bars will be used to bring the Gas in
  -> 2 independent gas cycles foreseen in the chamber to enhance redundancy;

Wire:

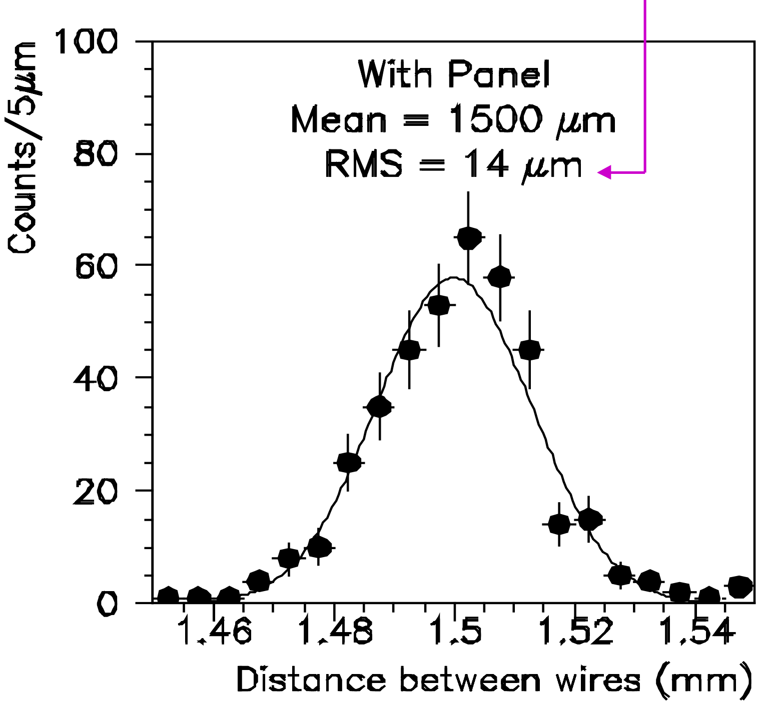
- Gold-plated tungsten wire of 30μm with 60±10g tension will be used

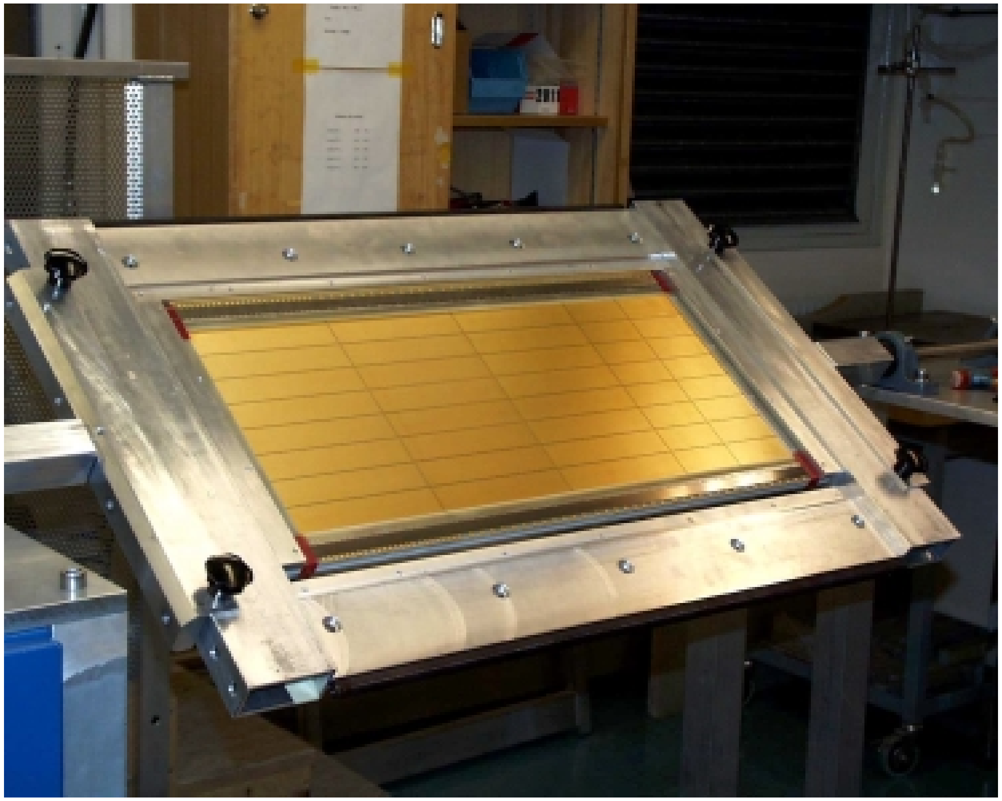


Chamber construction: Wiring

Required tolerances:

- Wire-cathode distance: 2.5±0.1mm
- Wire spacing: 1500±40μm



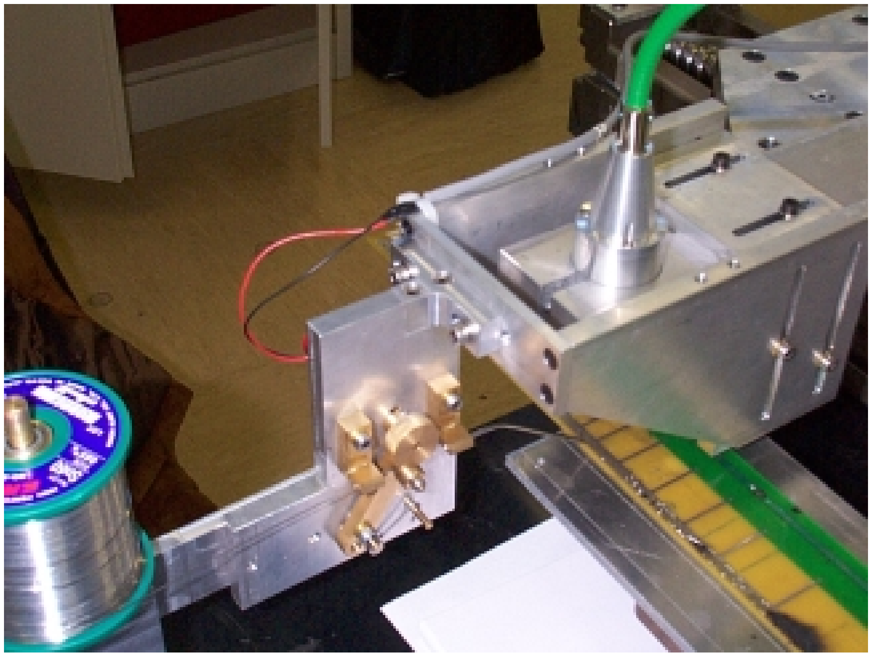


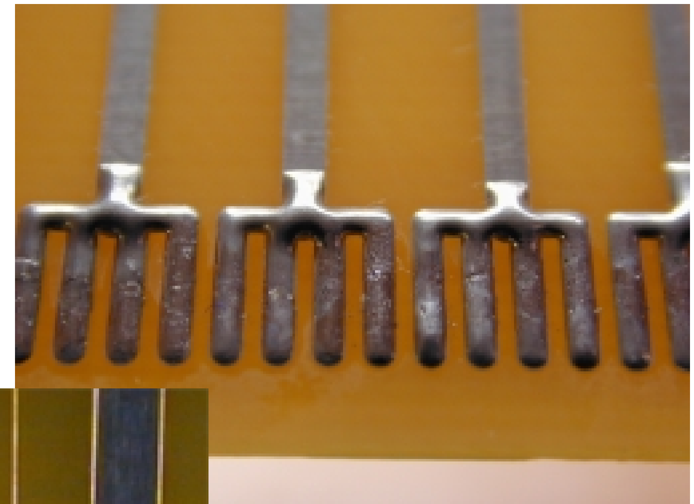
Chamber Construction: Wire Soldering

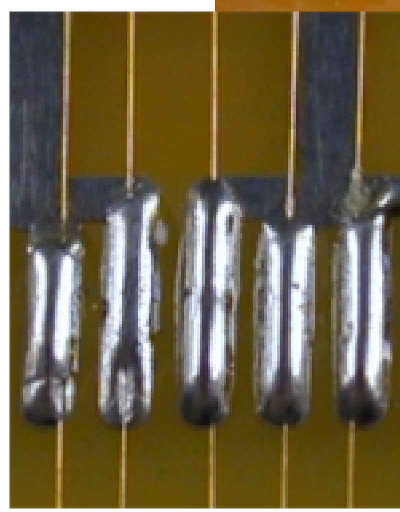
Number of wire soldering points: 4.86×10^6 !

-> Time consuming task in chamber construction (1.5mm wire spacing)

-> Automated soldering procedure mandatory for MWPC construction







Good results obtained with a laser beam

HV- and FE-Interface

HV-Interface:

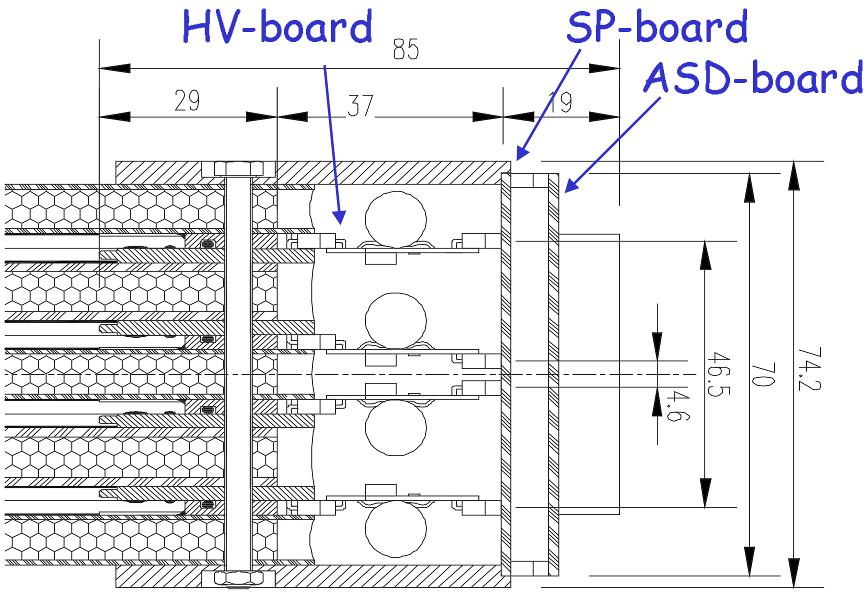
- Separate HV-board with capacitors (0.5-1nF) and resistors (100kΩ)

-> Modular system which allows tests prior to installation on chambers and easy replacement

FE-Interface:

- Maximal standardization with only few types of FE-boards
- Implementation in two stages:
  - Spark protection and ASD-board
- FE-board dimensions (70x50mm) given by space constraints
- Chamber border region constraints

-> Sum of both sides < 120mm

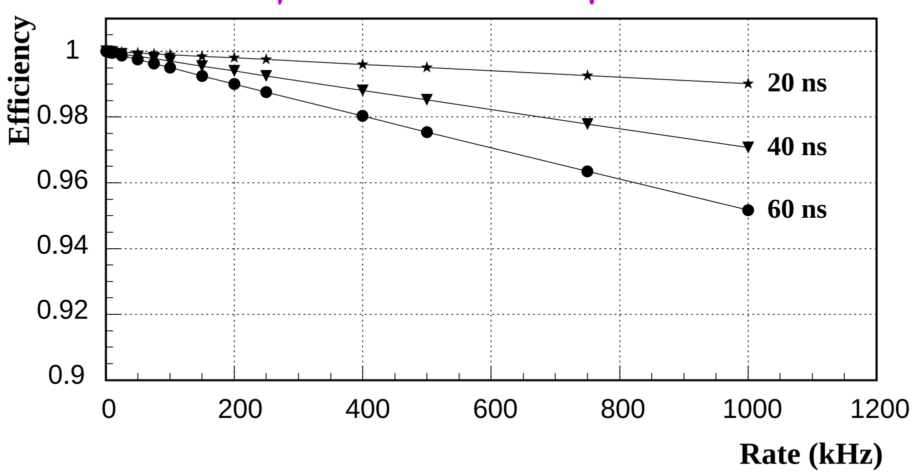


FE - Electronics

FE-chip specifications:

- **Peaking time** **~ 10ns**
- R_{in}: < 50 Ω
- C_{det} : 40-250pF
- Noise: <2fC for C_{det}=250pF
- Rate: up to 1MHz
- **Pulse width:** **< 50ns**
- Dose: up to 1Mrad

Inefficiency due to ASD pulse-width



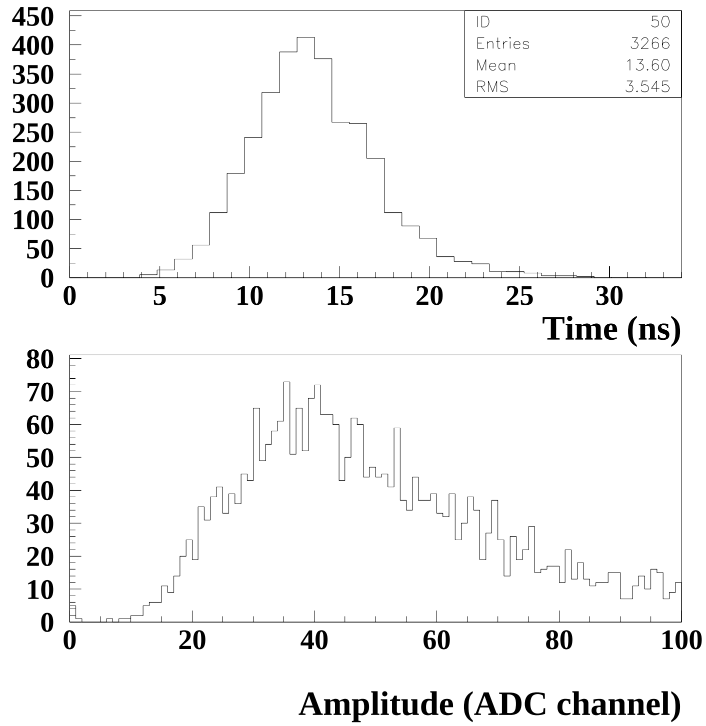
FE-chip candidates:

- PNPI SMD (reference)
- SONY++ (usable in some regions only)
- ASDQ++
  Modified version of ASDQ (**R_{in}=280Ω**)
  (**R_{in}=25Ω**, ENC: 1740+37e⁻/pF)
  -> Performs in general very well
- CARIOCA (0.25 μ CMOS, under dev.)
  t_p=7ns (pre-ampl.); R_{in}<20Ω;
  very low noise: 750+30e⁻/pF
  very low cost
  Design/Layout completed Sep.2001
  Final products: end 2002
  -> Preferred solution

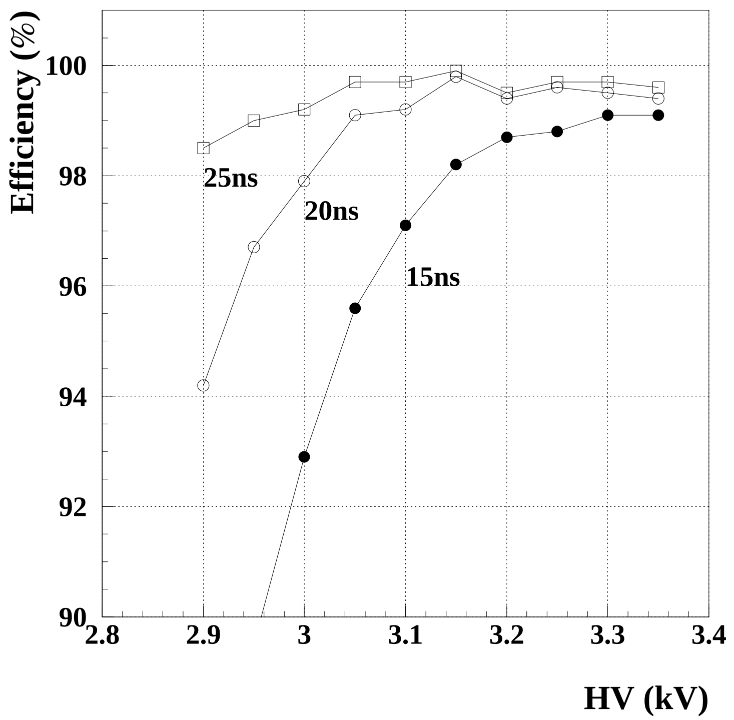
MWPC Prototype Tests

Performance results:

ADC and TDC Spectra



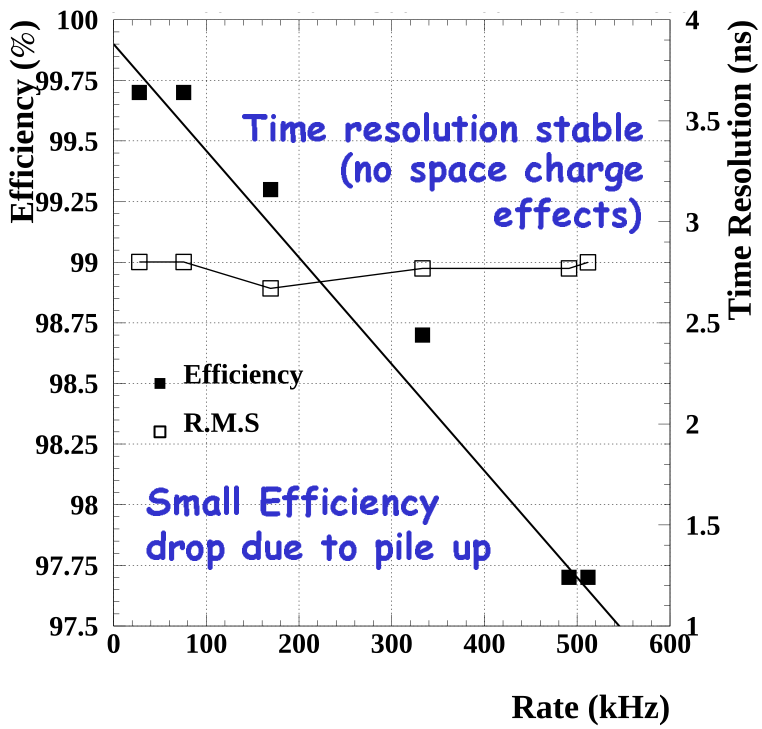
Efficency for different time windows



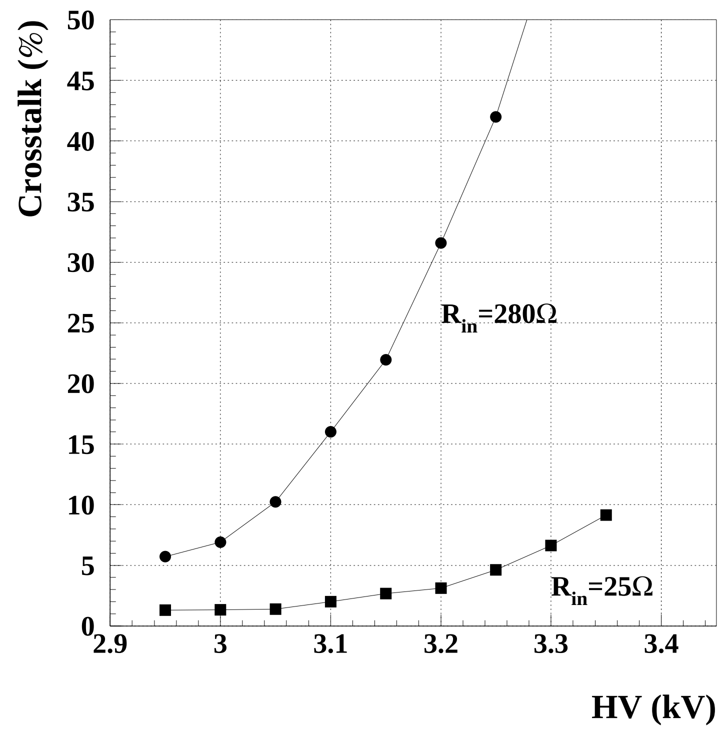
MWPC Prototype Tests

Performance results:

High rate performance



Cross talk between two 4x8cm Cathode pads

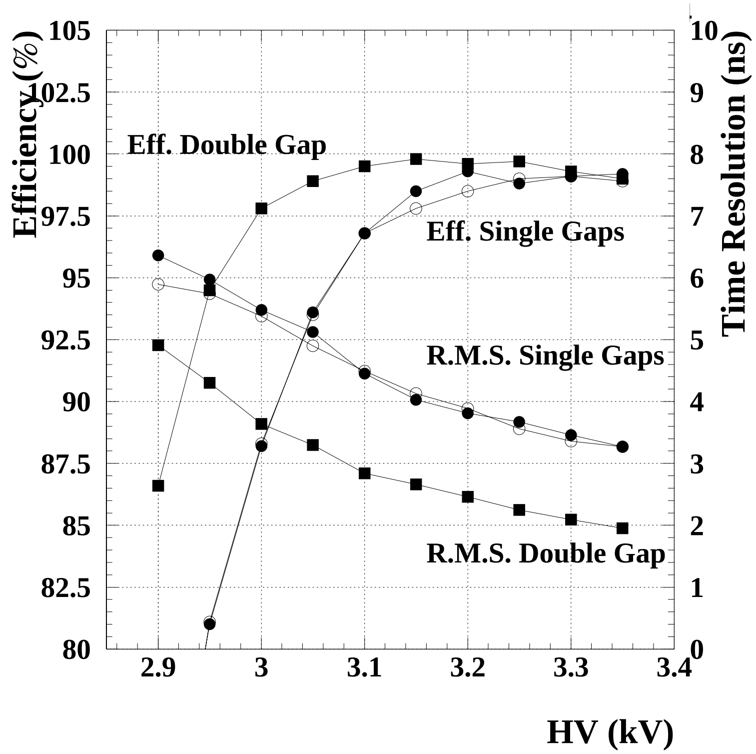


MWPCs satisfy all requirements for the Muon System with sufficient redundancy

MWPC Prototype Tests

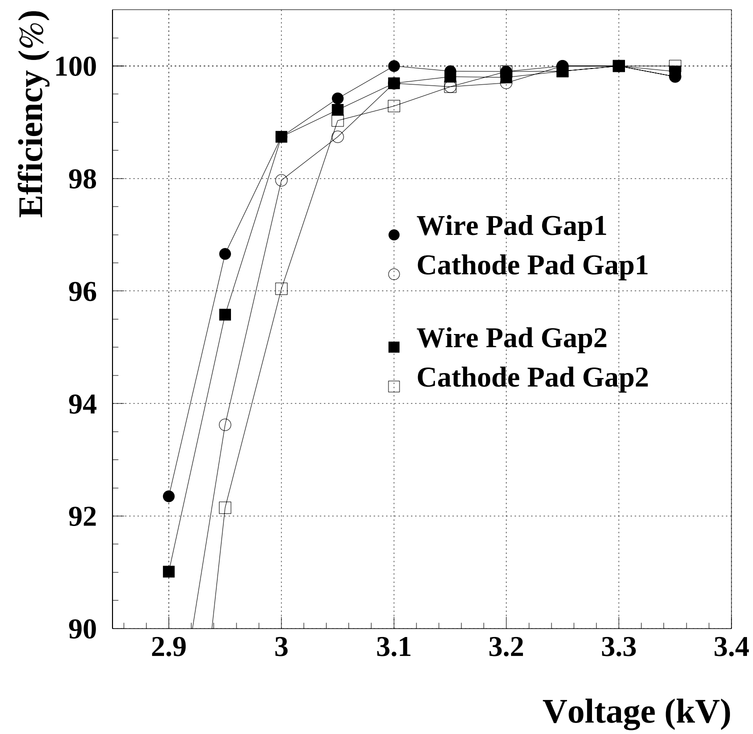
Performance results:

Anode readout, cathode grounded



Comparison of single and double gap readout

Combined Anode-Cathode readout



Anode and cathode efficiencies similar due to diff. thresholds