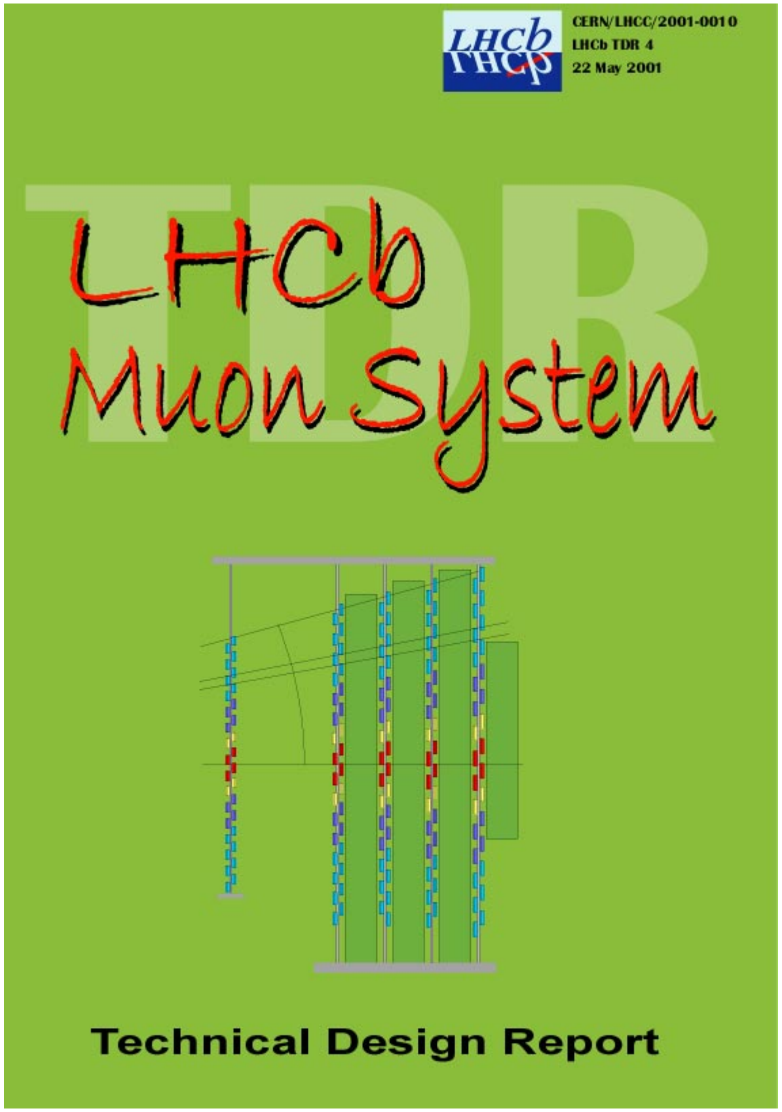
LHCb Muon System TDR

Schedule:

- **Discussion of TDR Draft 2**
  LHCb week 7-11 May 2001
- Comments from the collaboration
  until May 14
- Release of missing support notes
  until May 11/18
- Release of public version of support notes
  second half of May
- Preparation of final TDR version
  until May 17
- Submission to LHCC
  May 22 2001
- Presentation to LHCC
  4 July 2001



CERN/LHCC/2001-0010
LHCb TDR 4
22 May 2001

LHCb
Muon System

Technical Design Report

Muon TDR Contents

Outline:

1. Introduction (5 p.)
   - Physics requirements
   - General detector structure
   - Evolution since the TP
2. Detector Requirements and Specifications (10 p.)
   - Background environment
   - Muon system technologies
   - Readout electronics
   - Detector layout
3. Physics Performance (11 p.)
   - Simulation Procedure
   - Performance of the L0 muon trigger
   - Muon identification
   - Reconstruction of muonic final states ($B_d \to J/\psi K_s$; $B_s \to \mu\mu$)
   - Muon tagging

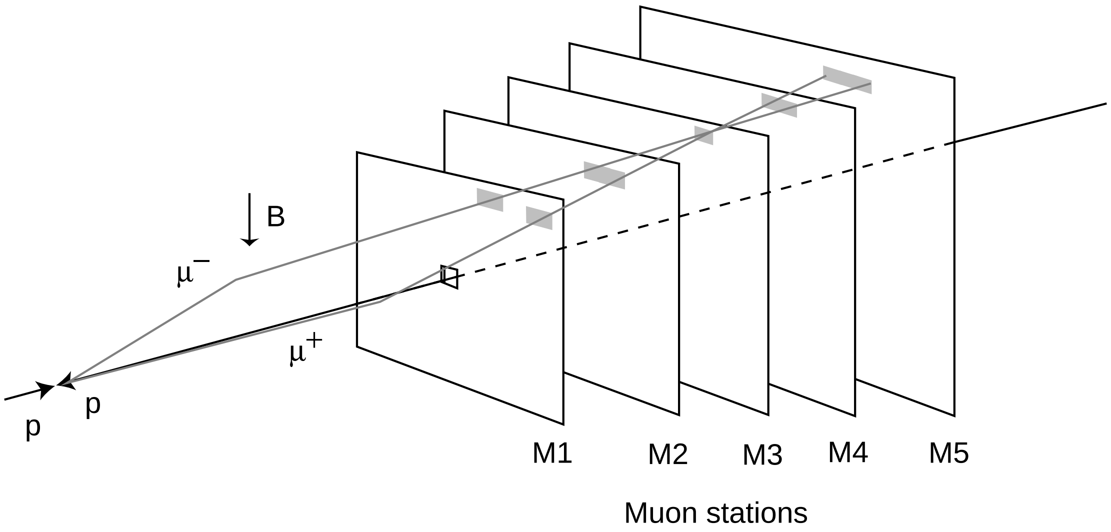
Muon TDR Contents

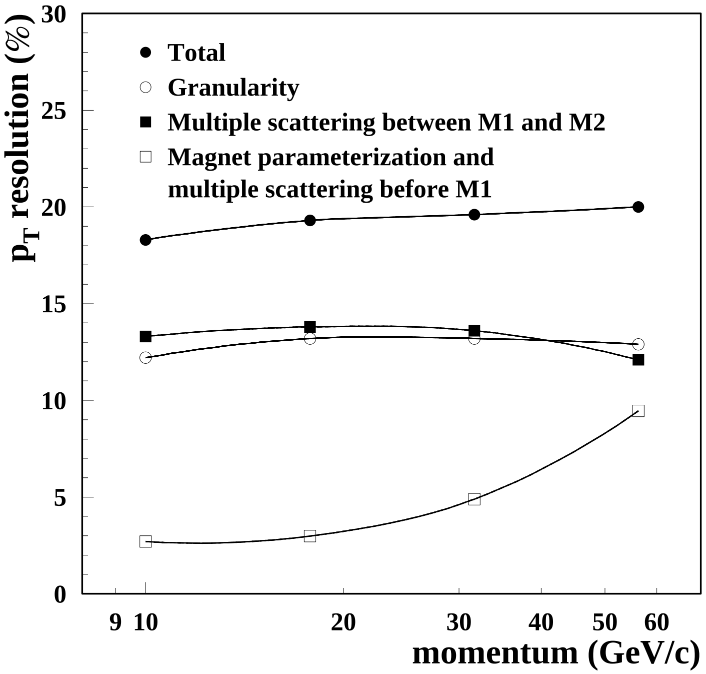
Outline (ctd.):

4. Prototype Results (12 p.)
   - FE-chip candidates
   - Results of MWPCs prototype tests
   - Results of RPC prototype tests
5. Technical Design (28 p.)
   - MWPC detector design and construction
   - RPC Detector design and fabrication
   - Readout Electronics
   - Support structures and installation
   - Service Systems (Gas and HV-System)
   - Safety aspects
6. Project Organization (6 p.)
   - Schedule and Milestones
   - Division of responsibilities
   - Cost

Physics Performance

Level 0 Muon Trigger:



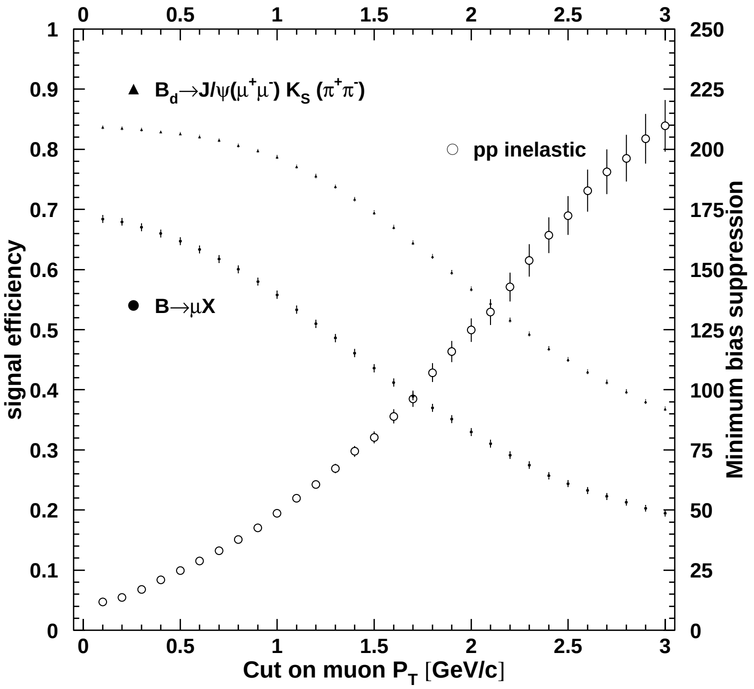


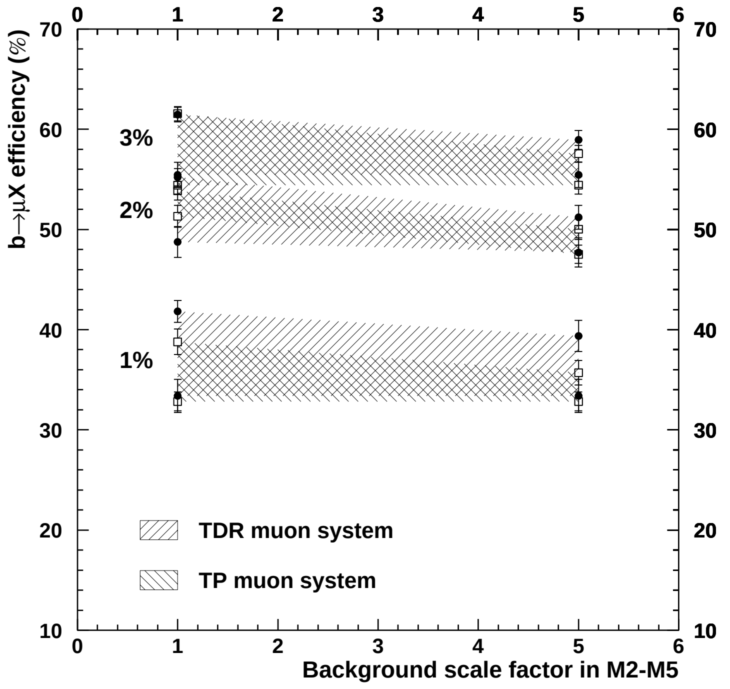
- Station M3: trigger seed
- Stations M2, M4 and M5: muon track finding
- Station M5: confirmation of penetrating particle (p > 5 GeV/c)
- Stations M1 and M2: used for the P_T-measurement

Level0 Muon Trigger

Results on Trigger Performance:

- TDR Muon system includes realistic chamber geometry and detector response (inefficiency, dead time, signal arrival time, noise, cross talk)



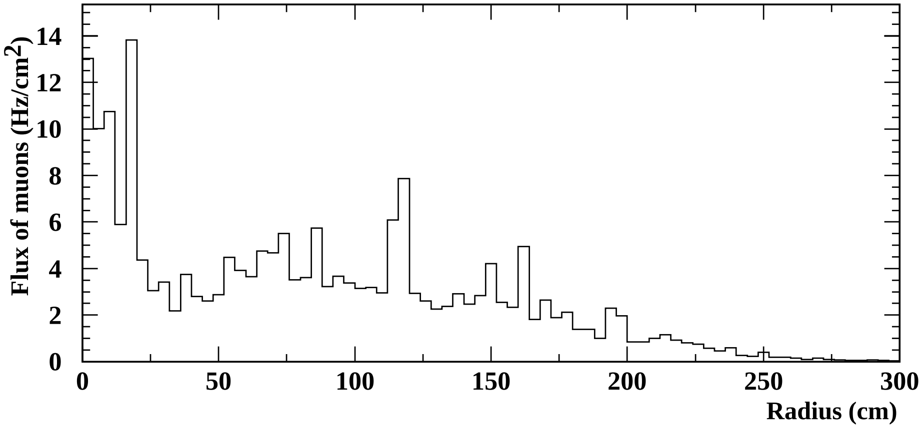


-> TDR Muon System is robust and shows slight improvement in performance compared to the TP Muon System

Level0 Muon Trigger

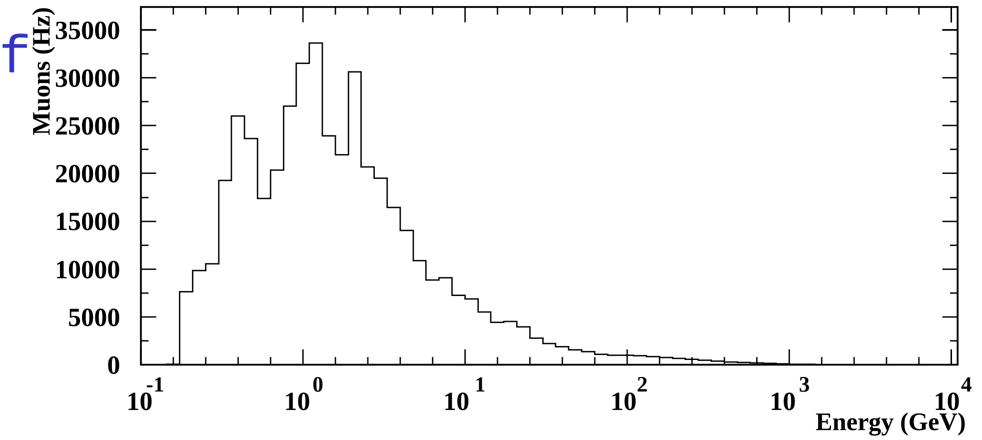
Beam halo muons:

- 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



- Halo muons are present in ~1.5% of the bunch crossings
- 80% of muons have p < 5 GeV/c
- In about 0.1% of the BXs halo muons cause a L0 muon trigger

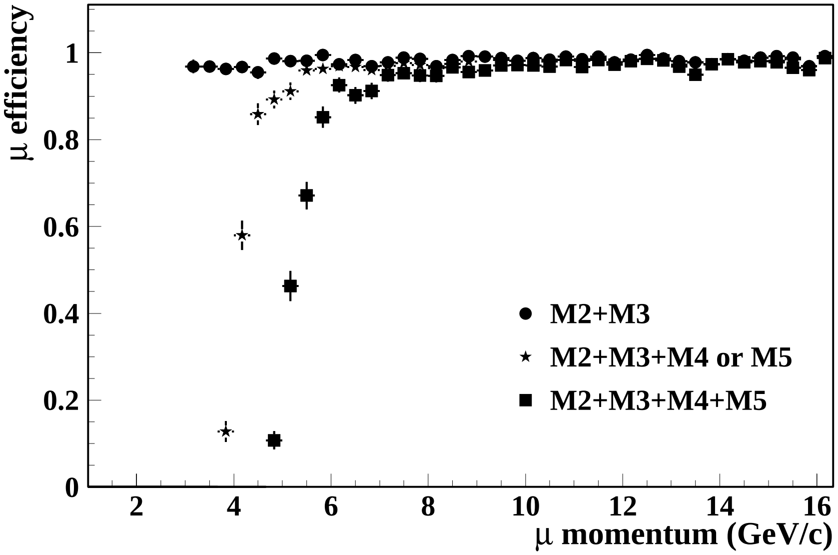
-> No significant effect



Muon Identification

Algorithm:

- Extrapolate reconstructed tracks with $p > 3$ GeV/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

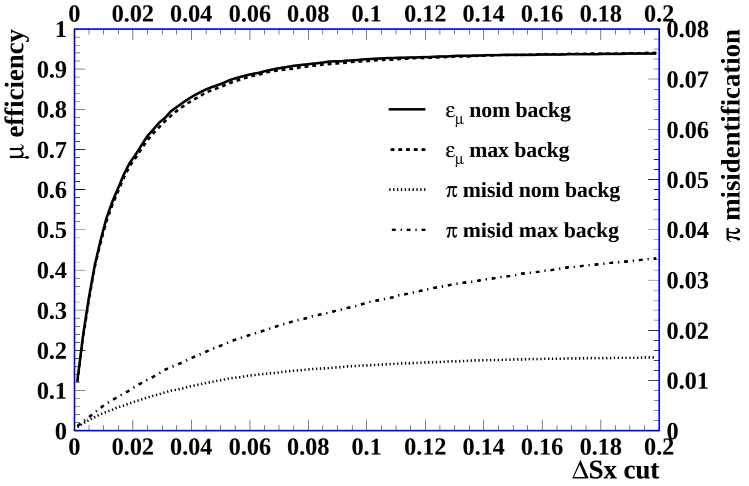


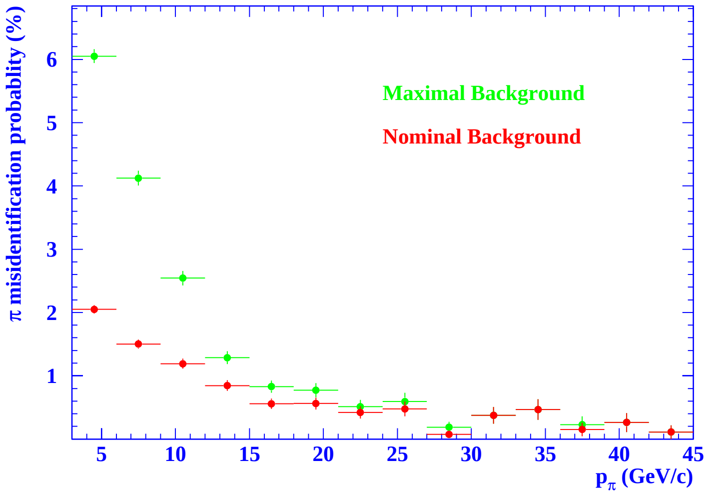
- M2+M3 for $3 < p < 6$ GeV/c
- M2+M3+(M4 or M5)
  for $6 < p < 10$ GeV/c
- M2+M3+M4+M5 for $p > 10$ GeV/c

Muon Identification

Performance:

	Nominal background	Maximal background
ε^{μ}	**94.0±0.3**	**94.3±0.3**
M^{e}	0.78±0.09	3.5±0.2
M^{π}	1.50±0.03	4.00±0.05
M^{K}	1.65±0.09	3.8±0.1
M^{P}	0.36±0.05	2.3±0.1





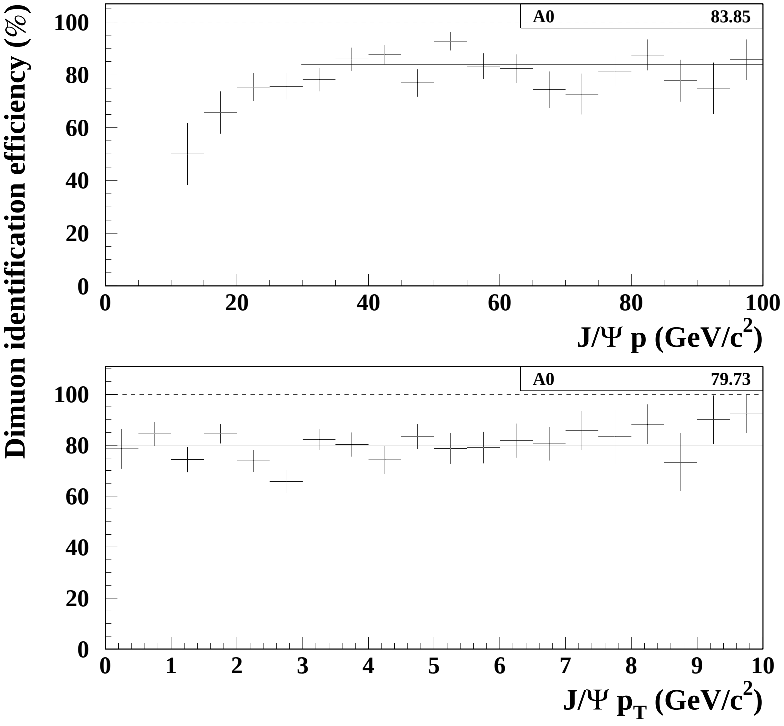
Additional cuts on slope difference ΔSx and p^{π} are required in case of large bkg. to keep M^{π} ~1% (ε^{μ} ~90%)

Muonic Final States

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

- Well established CP-violating decay from which angle β in the unitary triangle can be determined.
- J/ψ $(\mu^+\mu^-)$ reconstruction:
  - oppositely charged tracks identified as muons.
  - Mass of dimuon pair consistent with J/ψ mass
  - **-> Efficiency independent of p_T**
- Similar selection criteria for K_s and B^0
  - -> B^0 mass resolution 7 MeV/c^2
- L0 trigger acceptance of fully reconstructed events is 98%.
- L0 muon acceptance is 95%.
- ~40% triggered by muon trigger alone.

~120k events/year expected in LHCb



MWPC Detector

Performance requirements:

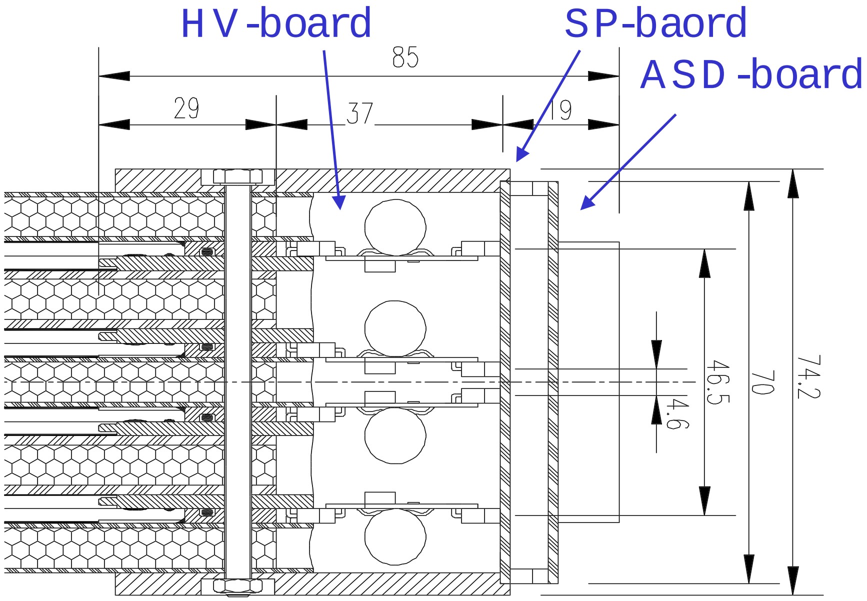
- Efficiency within 20ns time window >99% : -> Two gaps, 1.5mm wire spacing
- Redundancy: -> Two independent double gaps
- Good ageing properties: -> Gas mixture: Ar/CO_2/CF_4 40:50:10

Design Specifications:

- 30µm wire, 1.5mm wire spacing,
- 5mm gap size, 2x2gaps

Construction requirements:

Panel flatness:	±50µm
Gap size:	±70µm
Wire plane offset:	±150µm
Single wire offset:	±100µm
Wire pitch:	±40µm



Chamber Components

Panels:

- Key element in MWPC, ±50µm precision over 40cm x 140cm required
- Nomex Honeycomb panels are baseline choice.
  - Good experience in tests have been made.
  - Light, robust, good glueing properties.
  - Precision panels are expensive
- Other materials like Chempir core and polyurethanic foam under consideration

Frames:

- Solution which does not require precision on wire fixation bars has advantages

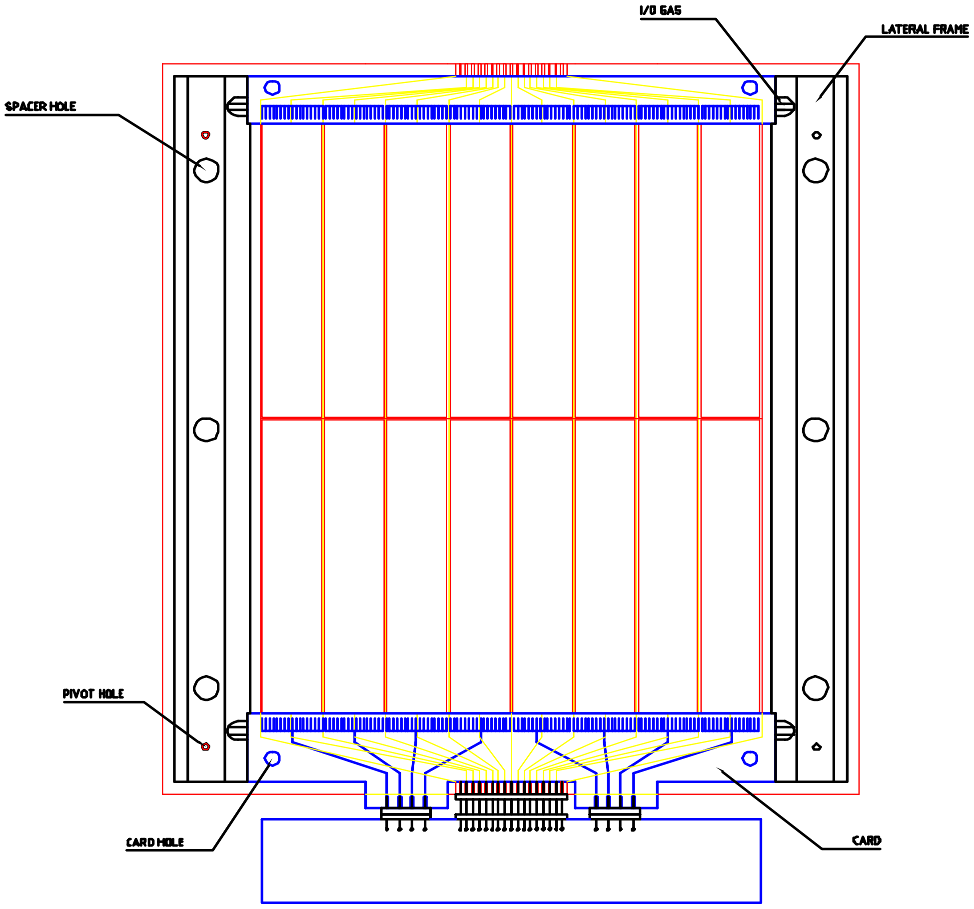
  ->Precision could come from spacers introduced every 10-15cm in the frames
- Signals for subsequent connector are grouped on wire fixation bars
- Side bars will be used to bring the Gas in

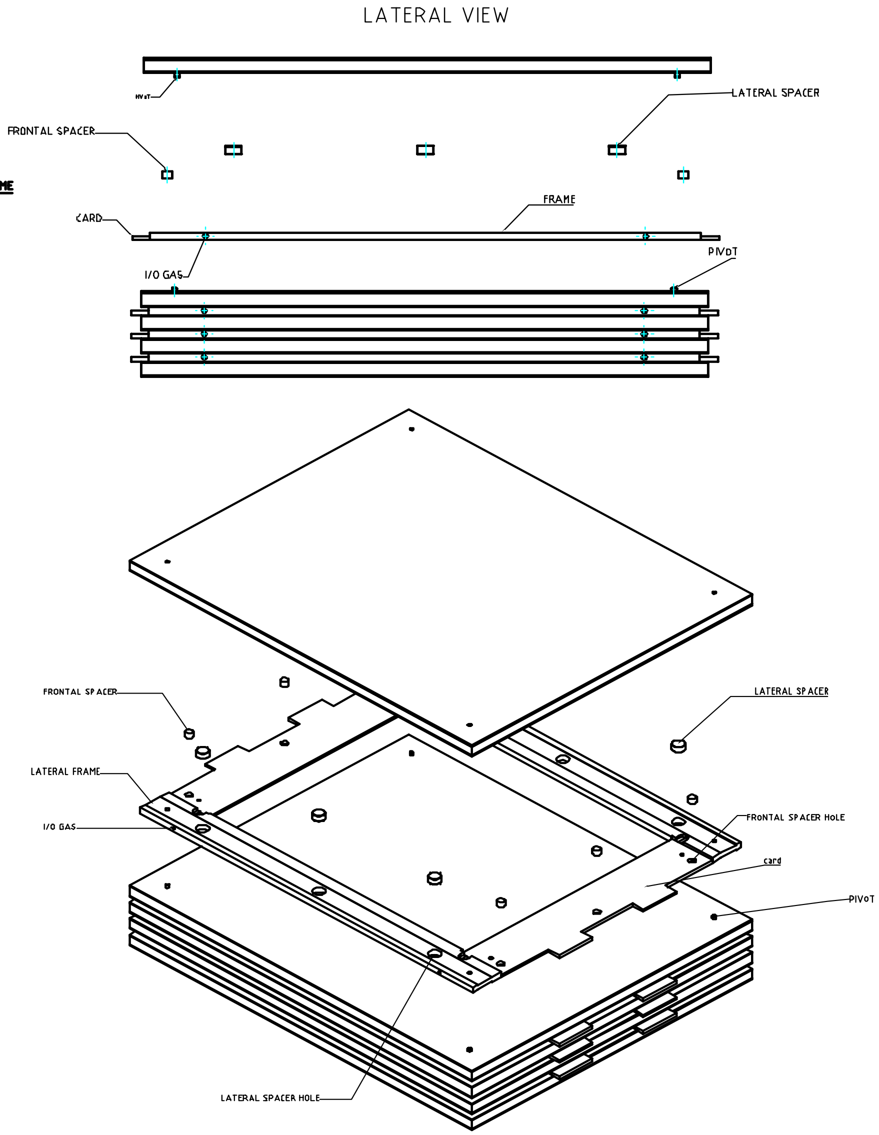
  ->2 independent gas cycles foreseen in the chamber to enhance redundancy;

Wire:

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

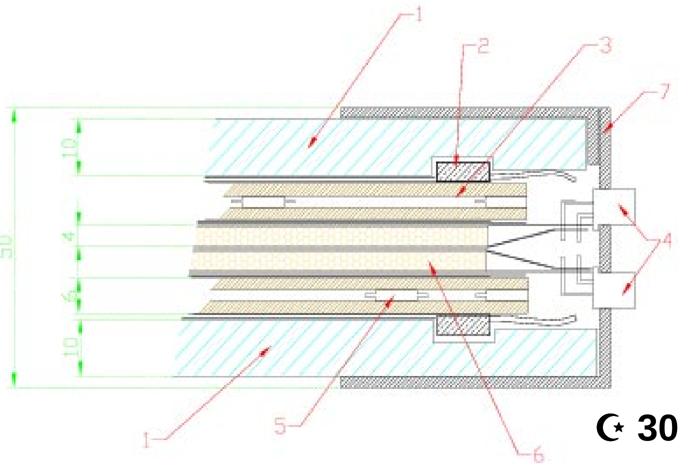
Chamber Design

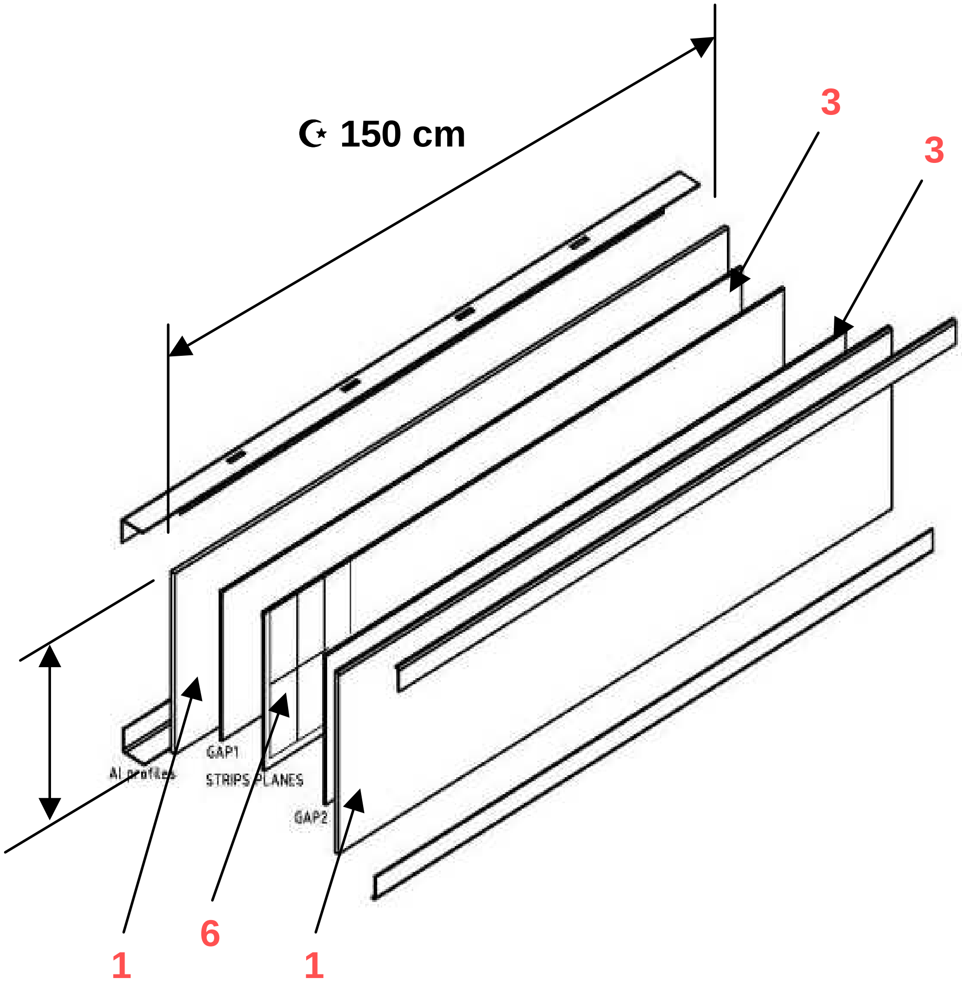




RPC design

1. Al-poly sandwich
2. HV connection
3. Gas-gap
4. Output connectors
5. Spacing button
6. Strip planes
7. Al box





≈ 30 cm

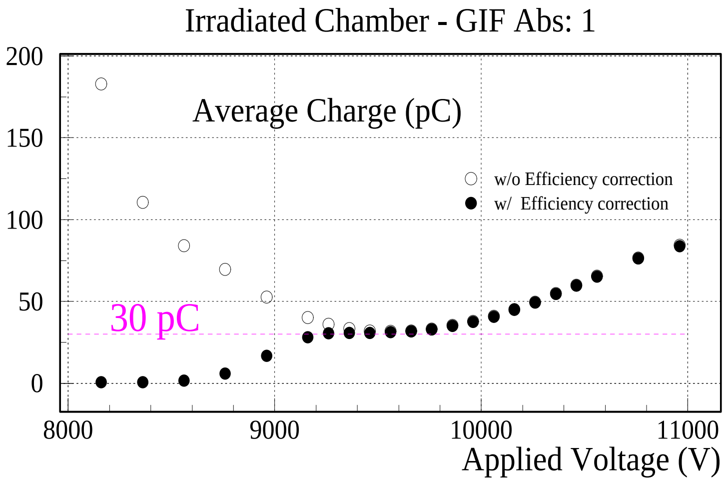
All gas-gaps same size

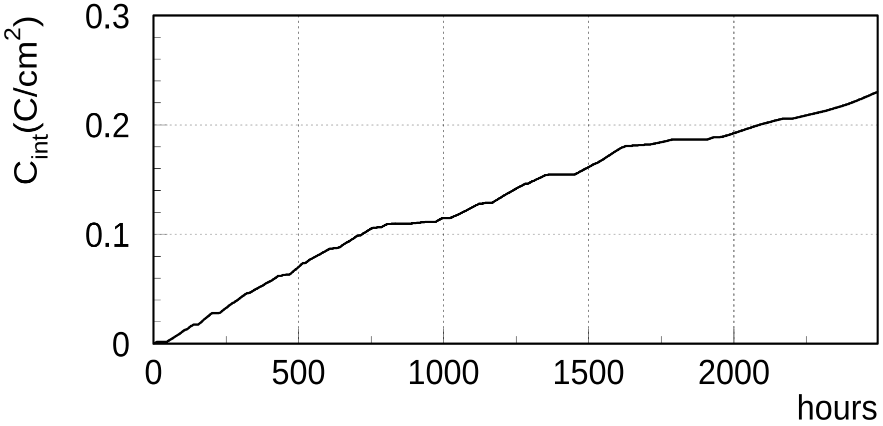
GIF Ageing Test

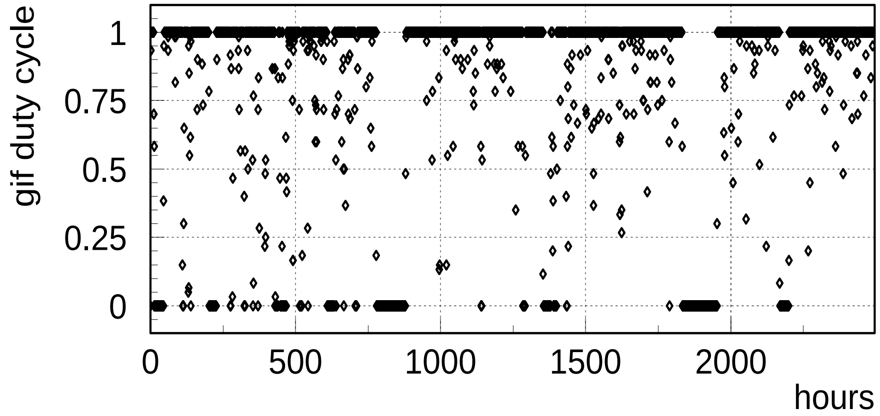
Ageing requirements in LHCb
(including safety factors)

	Region 3	*Region 4*
J_{max}	11 nA cm^{-2}	4 nA cm^{-2}
Q (10 y)	1.1 C cm^{-2}	0.4 C cm^{-2}

Avalanche charge: GIF measurement



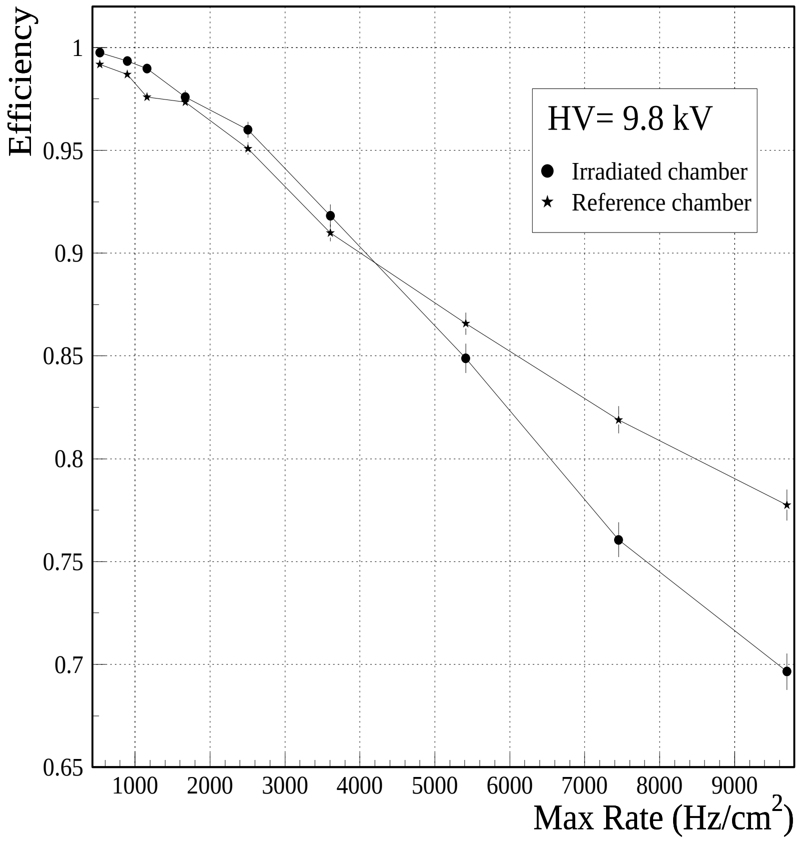




GIF test: started Jan. 15, to continue up to December

GIF Ageing Test

Rate capability measurement after accumulating 0.2 C cm^{-2} (☪ 5 LHCb years in Region 4)



No effect up to 3.5 kHz cm^{-2}

Oil vs. No-Oil

Linseed oil on bakelite

improves

✓
- **Noise (less load on trigger)**
- **Dark current (less ageing)**

could introduce problems (Babar)
- **Polymerization critical**

⚠ **is an additional variable**
- construction more delicate
- extra quality control req'd

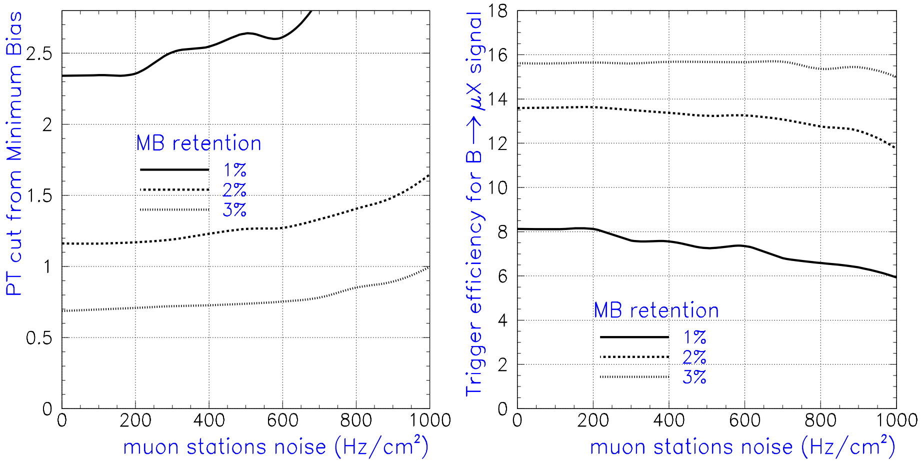
Current and noise ok with oil. However we favor a solution without oil.

Milestones (December 2001)

$I_{DARK} < 2\ nA/cm^2$ $(20\ \mu A/m^2)$

Dark rate $< 200\ Hz/cm^2$

➡



RPC Quality Control and Testing

Bakelite

Measurement of volume resistivity ← **Performed at bakelite factory**

Measurement of surface roughness

Gas Gaps

Check of oil layer (if used)

Check of gas tightness and HV leaks (at the factory)

Measurement of I vs. HV curve, reject gaps with too high dark currents

Check uniformity with source

Pairing of similar gaps

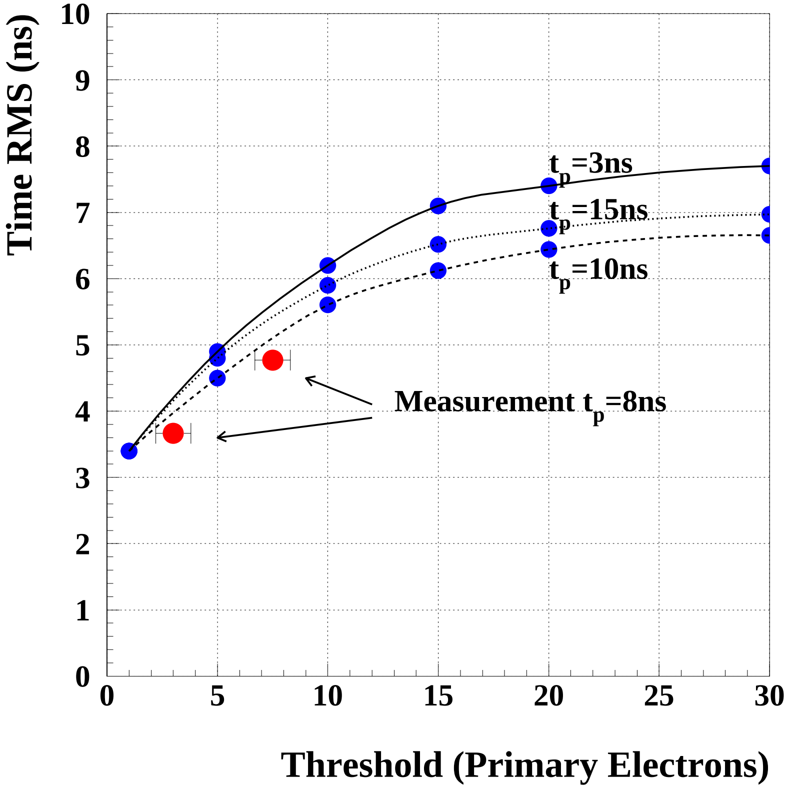
Chambers & Electronics

Cosmic ray test of the assembled chamber

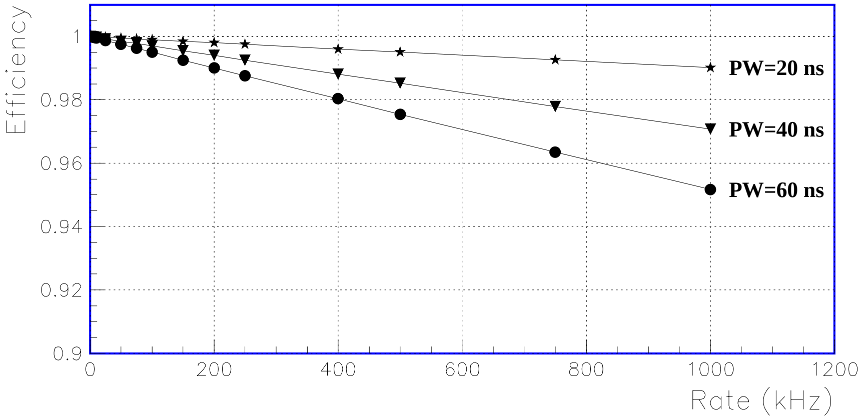
FE - Electronics

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 - Electronics

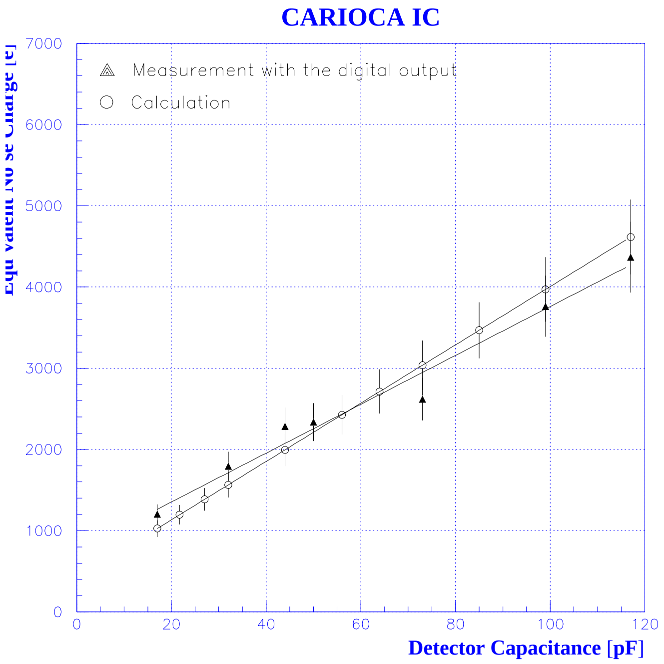
FE-chip candidates:

- PNPI SMD (reference) **(t_p=8ns, R_{in}=25Ω,** ENC:1250+50e^-/pF)
- SONY ASD **(pulse width ~90ns, radiation limit ~ 50krad)**

  SONY++ (adapted version of SONY ASD, usable for some regions)
- ASDQ **(R_{in}=280Ω, requires modification.)**

  ASDQ++ **(R_{in}=25Ω,** ENC:1740+37e^-/pF)

  ->Performs in general very well



- CARIOCA (0.25 µ CMOS, under development)
  - **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

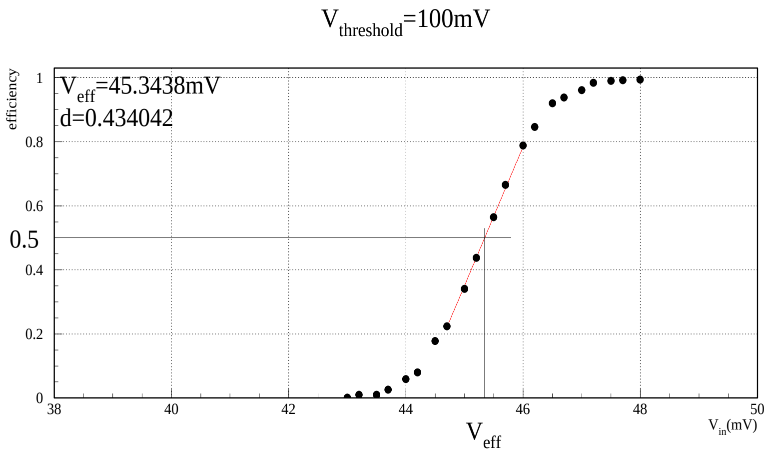
  -> Prefered solution

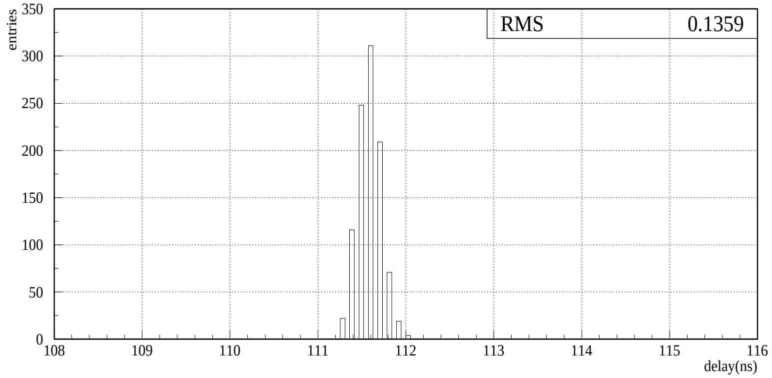
FE electronics

Baseline choice: CMS BiCMOS chip

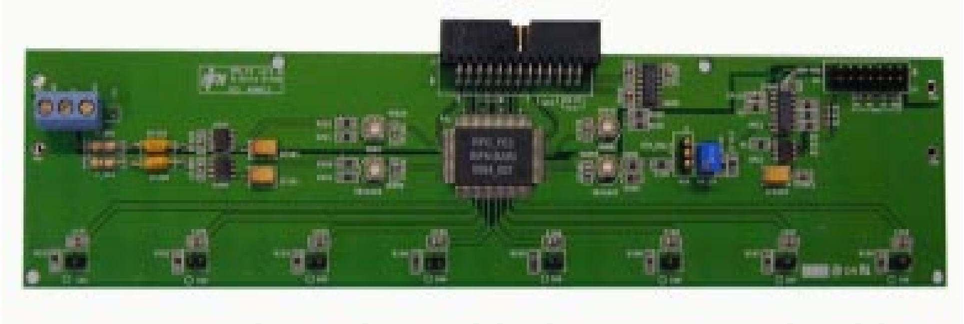
Technology	**0.8 um BiCMOS**
Dimensions	**2.9x2.6 mm**
Input impedance	**15 ohm**
Dynamic range	**20 fC - 20 pC**
Charge sensitivity	**1 mV/fC**
Equiv. Input noise	**4 fC**
Ch. to ch. time spread	**< 0.35 ns**
Dead time	**50 ns**
Power consumption	**45 mW/channel**

Chip calibration





LVDS output



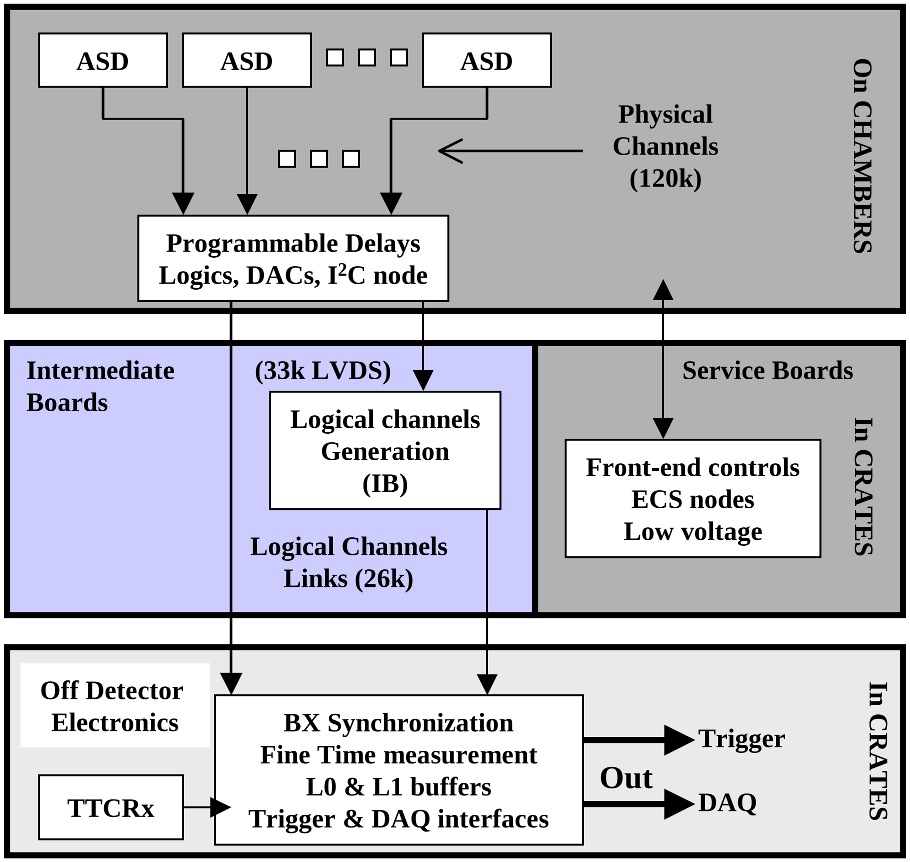
Prototype board used in beam tests (8 ch)

Final board will be 16 ch

Readout Electronics

System Architecture:

- FE-boards: 7536
  (with ASD and DIALOG chips)
  120k phys.ch. 43k log.ch.
- Service Boards: 144
  (with CAN-ELMB nodes)
- Intermediate boards: 168
  26k log.ch.
- Off Detector Elec.Boards: 168
  (with SYNC chips/FPGAs)



ASD

ASD

ASD

Physical
Channels
(120k)

On CHAMBERS

Programmable Delays
Logics, DACs, I^{2}C node

Intermediate
Boards

(33k LVDS)

Logical channels
Generation
(IB)

Logical Channels
Links (26k)

Service Boards

Front-end controls
ECS nodes
Low voltage

In CRATES

Off Detector
Electronics

TTCRx

BX Synchronization
Fine Time measurement
L0 & L1 buffers
Trigger & DAQ interfaces

Out

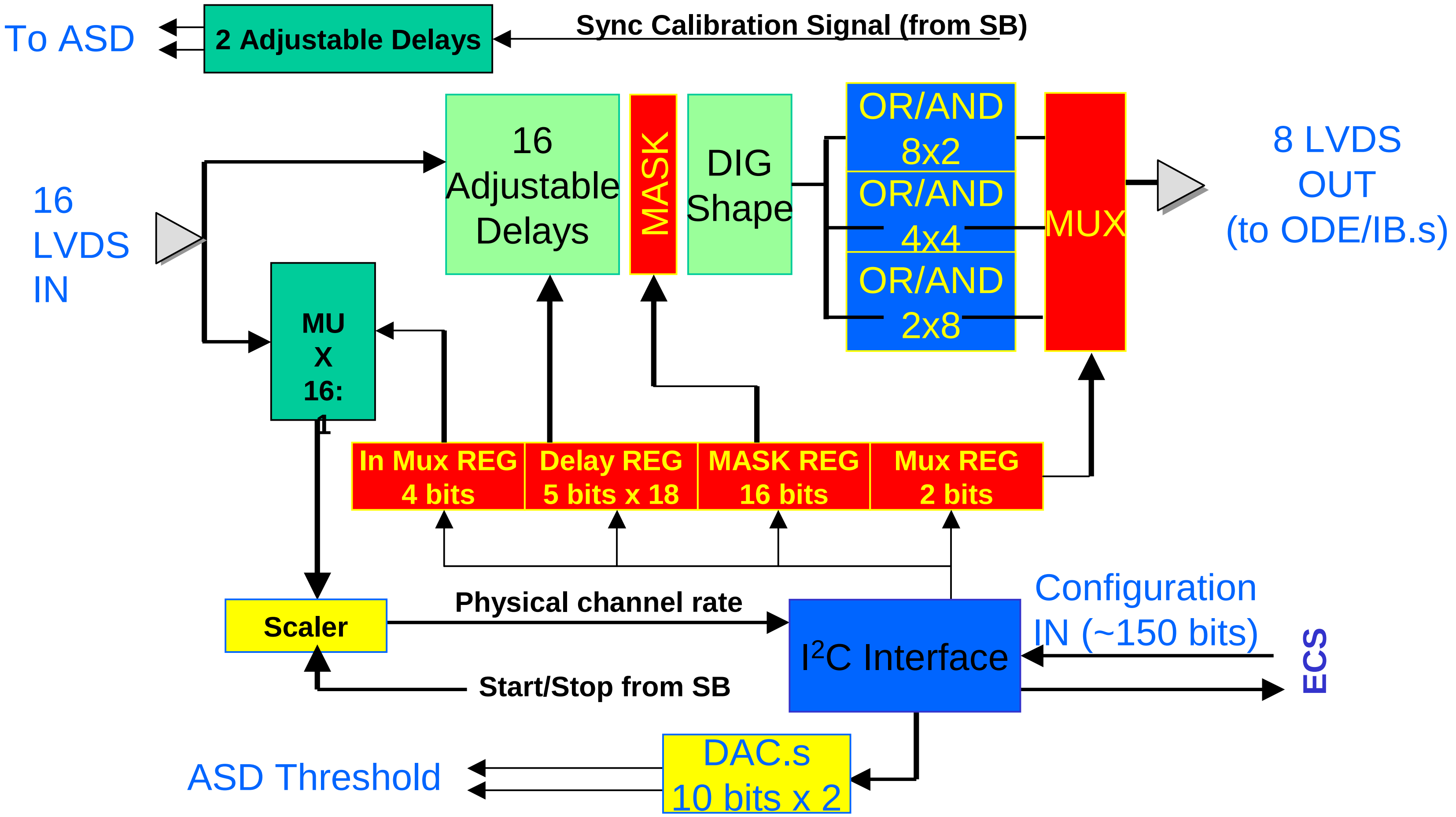
Trigger

DAQ

In CRATES

DIALOG

DIagnostics, time Adjuster and LOGics



To ASD

2 Adjustable Delays

Sync Calibration Signal (from SB)

16 LVDS IN

16 Adjustable Delays

MASK

DIG Shape

OR/AND 8x2

OR/AND 4x4

OR/AND 2x8

MUX

8 LVDS OUT (to ODE/IB.s)

MUX 16:1

In Mux REG 4 bits

Delay REG 5 bits x 18

MASK REG 16 bits

Mux REG 2 bits

Scaler

Physical channel rate

Start/Stop from SB

I²C Interface

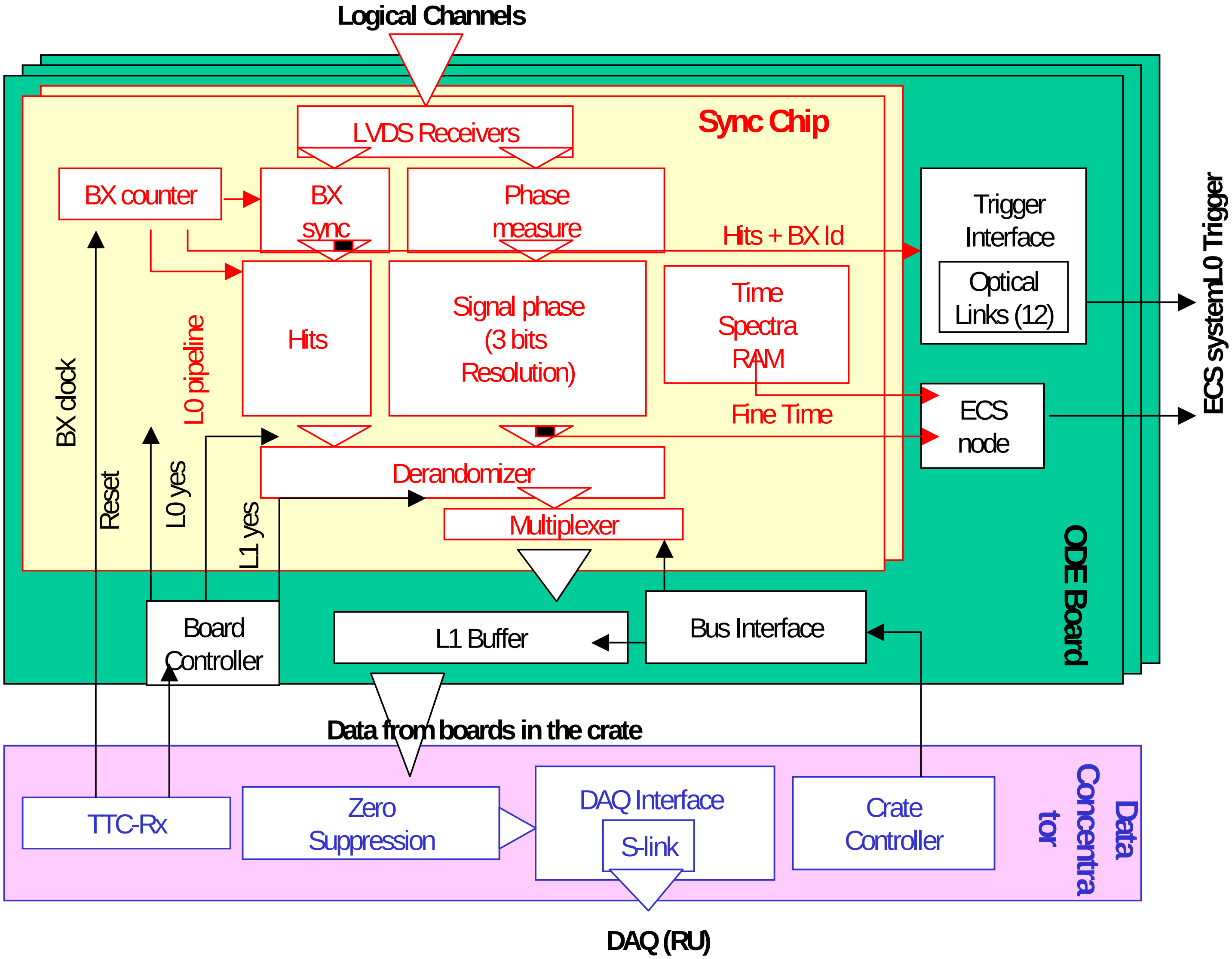
Configuration IN (~150 bits)

ECS

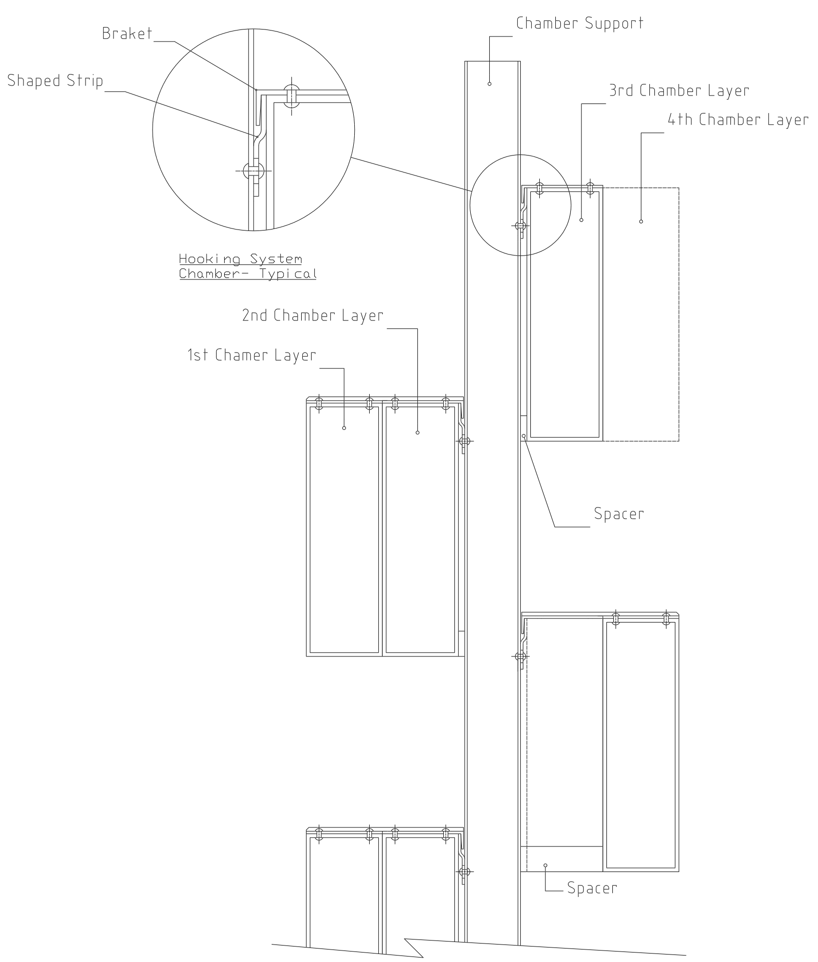
DAC.s 10 bits x 2

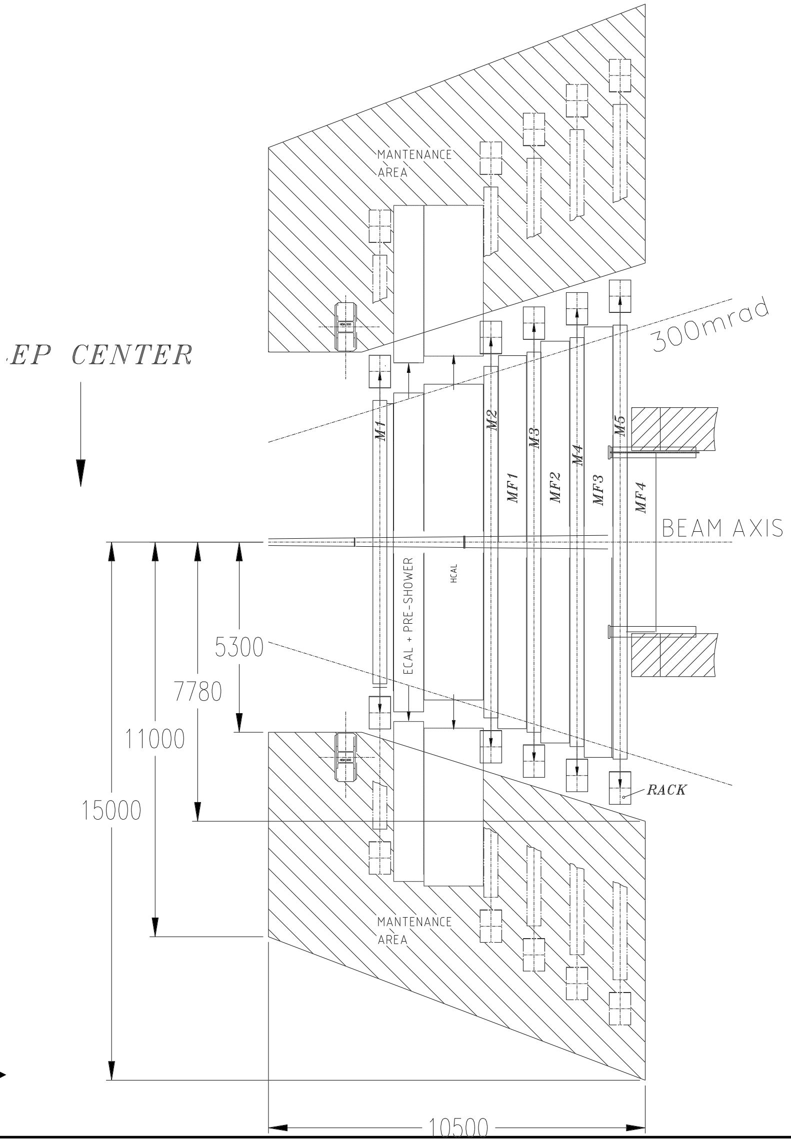
ASD Threshold

OFF Detector Electronics



Support Structures





Discussions with cryo-group etc.
on space situation continue →

Muon Detector Milestones

Date	Milestone
	MWPC Detectors
2002 Apr	Engineering design completed
2003 Feb	Begin chamber construction and tests
2004 Dec	Chamber construction completed
	RPC Detectors
2001 Dec	Decision on oil
2002 Apr	Engineering design completed
2003 May	Begin chamber construction and tests
2004 Dec	Chamber construction completed
	Chambers for the inner part of M1
2003 Feb	Technology choice
2004 Dec	Chamber construction complete
	Electronics
2002 Mar	CARIOCA and DIALOG design and test completed
2002 Nov	Full chain electronics test completed
2003 Feb	Begin FE-board production
2002 Nov	Begin IM, SB, ODE boards preproduction
2004 Dec	Electronics assembled and tested
	General infrastructure
2003 Dec	Iron filter installed
2004 Jun	Chamber support structure installed
	Muon Detector
2005 Aug	Commissioning completed

Sharing of Responsibilities

Task	Institutes
MWPC Detectors	
M1-M3 outer part	Ferrara, LNF, PNPI, Rome I/Potenza
M2-M5 inner part	CBPF, CERN, Ferrara, LNF, UFRJ
RPC Detectors	
M4-M5 outer part	Firenze, Roma
II	
Inner part of M1	
	Cagliari, LNF
Electronics	
CARIOCA chip	CERN, UFRJ
DIALOG chip	Cagliari
MWPC FE Boards	CBPF, PNPI, Rome I/Potenza, UFRJ
RPC FE Boards	Firenze, Roma II
IM Boards	LNF
Service Boards	LNF
ODE Boards (+SYNC chip)	Cagliari, LNF
Services	
Gas system (design)	CERN
Monitoring, control (ECS)	Roma I
Experimental area infrastructures	
Chamber supports	CERN, LNF
Muon filter	CERN

Project Costs (kCHF)

Item	Cost
MWPC Detectors	**1220**
RPC Detectors	**260**
Electronics	**4040**
Services (*)	**1310**
Muon filter	**4000**
TOTAL COSTS (incl. Spares & Contingency)	**10830**

(*) Gas and HV systems + support structures