8 MUON simulation

8.1 RPC Muon Trigger Software

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The RPC Muon Trigger package is called MRPC. Its present version (November 1998) is designed to work within the framework of CMSIM version 113 and higher.

8.1.1 RPC Trigger Idea

The idea of the RPC based trigger for CMS is illustrated in Fig. 1. The solenoidal field bends tracks in the $r\phi$ plane. A pattern of hits recorded by RPC's carries the information about the bending, and can be used to determine p_t of the track. This is done by comparison with a predefined set of patterns corresponding to various p_t. Therefore we call this device Pattern Comparator Trigger (PACT).

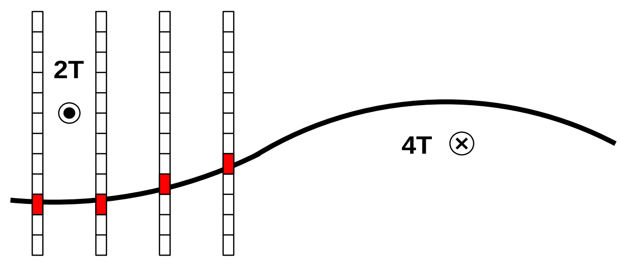

Figure 1: RPC Pattern Comparator Trigger principle.

The trigger is based on 4 RPC planes. There is one RPC plane in each muon station except MB1 and MB2. These stations contains additional planes referred to as MB1' and MB2'. They are used to trigger on low momentum muons ($p_t < 5$ GeV) which cannot reach MB3 and MB4. In the baseline design RPC cover the η-range up to $|\eta|$=2.1, but the space is left up to $|\eta|$=2.4 for a possible upgrade. RPC are read out by strips covering $\Delta\eta \approx 0.1$ and $\Delta\phi = 5/16°$ each. If the signal is shared by more than 2 strips the cluster size is reduced by removing extreme strips. For low p_t muons, when the resolution is limited by multiple scattering, the strips are grouped by 2, 4 or 8, depending on the momentum.

The basic logical unit of PACT is called segment. It covers $\Delta\eta \approx 0.1$ rapidity unit $\times$ $\Delta\phi = 2.5°$. It is defined by 8 strips in a reference muon station. As the reference station we have chosen ME2 and the first RPC plane in MB2. Each segment processor is equipped with a Pattern Comparator (PAC) chip which compares patterns of hits from 4 RPC planes with predefined valid patterns. The valid patterns are first obtained from simulation and will be corrected later using real reconstructed muon tracks. Because a given pattern can be created by muons from a certain p_t range we assign a maximal p_t value to it. The pattern must consist of at least 3 hits from different planes. If it consists of 4 different plane hits a quality bit is set to 1. Otherwise it is set to 0.

8.1.2 Simulated geometry and numbering schemes

The physical segmentation of RPC strips in the barrel is projective in ϕ and z. In the endcaps it is projective in ϕ and r. Since each strip has $\Delta\phi = 5/16°$ the strips are numbered from 0 to 1151 following the ϕ coordinate. The exact position of the RPC in the endcaps and η-divisions of strips are still under optimisation. Therefore, details of the geometry described below should be considered only as an example. Actual values can be found in $CMS_VROOT/cmsim/mrpc/rpcdes/mrpar3.inc

The CMS barrel consists of 5 wheels containing 4 muon stations each. RPC in each wheel are divided in 3 along z. Thus the barrel is divided in 15 *rolls* numbered from -7 to 7. Correspondence between the roll number and the z coordinate is given in Tab. 1.

In the endcaps the strip division lines are parallel to the beam. Hence each endcap roll is a set of strips contained by a cylinder of inner radius r_{min} and outer radius r_{max}, as defined in Tab. 1. The forward endcap rolls are numbered from 8 to 23 and backward endcap rolls — from -23 to -8.

The logical segmentation of the PACT trigger is projective in ϕ and η. It is defined by the strips in the reference plane, i.e. MB2 and ME2. The logical ϕ segmentation just follows the physical one. One trigger segment is based on 8 reference strips, hence segments are numbered from 0 to 143. The η segment boundaries are given in Tab. 1.

Table 1: Physical segmentation of RPC strips.

roll	0	1	2	3	4	5	6	7
z_{min}	-43	43	148	233	318	415	500	585
z_{max}	43	128	233	318	403	500	585	671
η_{min} (MB2)	-0.09	0.09	0.28	0.47	0.63	0.78	0.92	1.04
η_{max} (MB2)	0.09	0.28	0.47	0.63	0.78	0.92	1.04	1.14
roll	8	9	10	11	12	13	14	15
r_{max}	695	595	540	492	438	392	351	299
r_{min}	595	540	492	438	392	351	299	264
η_{min} (ME2)		1.14	1.22	1.30	1.40	1.50	1.60	1.75
η_{max} (ME2)		1.22	1.30	1.40	1.50	1.60	1.75	1.87
roll	16	17	18	19	20	21	22	23
r_{max}	264	233	208	187	169	154	141	128
r_{min}	233	208	187	169	154	141	128	116
η_{min} (ME2)	1.87	1.99	2.10	2.20	2.30			
η_{max} (ME2)	1.99	2.10	2.20	2.30	2.40			

The segments in η form 39 *rings* (sometimes called η-*towers*) which are numbered from -19 to 19 as shown in Fig. 2.

In every ring 4 RPC planes are chosen to be connected to the segment processors. The chosen planes are indicated in Fig. 2. In the barrel there are additional low p_t (> 5 GeV) processors receiving signals from MB1, MB1', MB2 and MB2' planes.

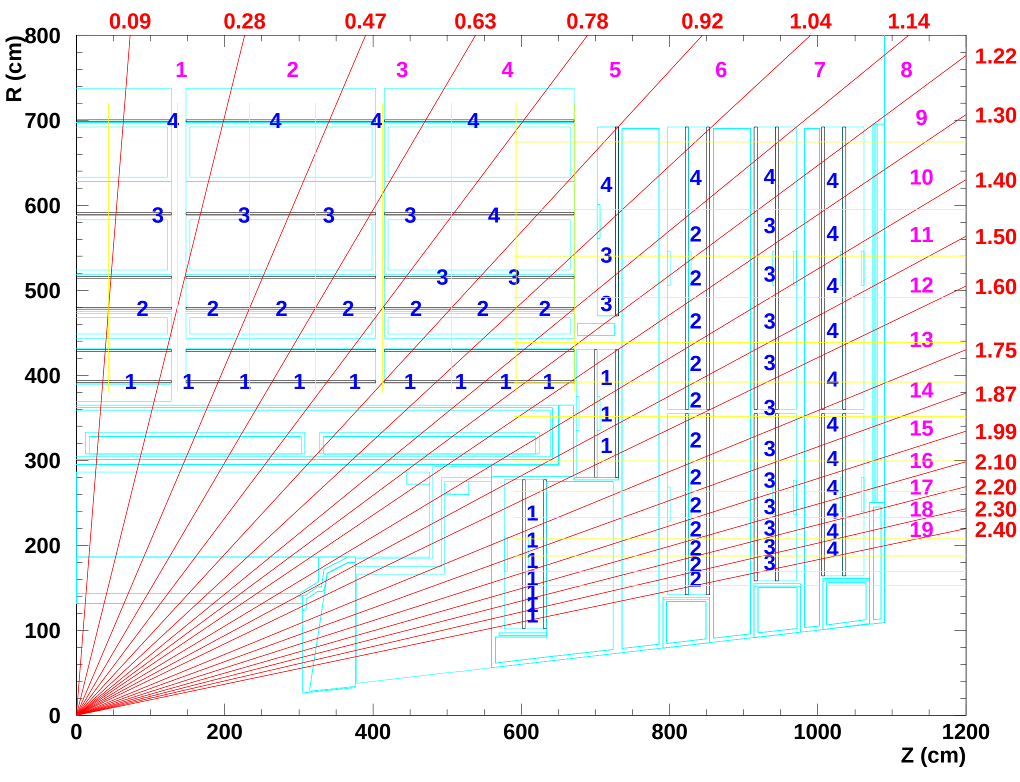

Figure 2: Physical segmentation of RPC chambers and logical segmentation of PACT.

8.1.3 The MRPC software

The RPC Trigger software is placed in the cmsim/mrpc repository. It contains the following directories:

- rpcdes: include files (geometrical parameters, algorithm parameters, etc.)
- rpckit: the actual RPC simulation routines
- rpcuty: utility routines (printouts, histogramming, etc.)
- rpcusr: empty directory, to used for developement
- rpcpar: parametrisation routines to be used for fast simulation

The core of the package consists of three parts:

- initialisation
- RPC digitisation
- RPC trigger simulation

Initialisation

Definition of control card MRPC:
MU_FFKEY → MU_FFKEY_RPC
For the card syntax and defaults see Section 8.1.4
Reading in input file:
M_INITG → M_INITG_RPC
An ASCII files is foreseen to be in the directory $CMS_DB/muon with a default name mrt1.dat, controlled by keyword MRT1. It containes the list of valid patterns.

RPC digitisation

Flow chart: GUDIGI → CMH2D → MRDIGI → MRHFILL1
The following geometry information is used:

1. IDTYPE = IDRPCB, IDRPCF for barrel and forward region respectively.
2. Sensitive volume names as listed in $MRPAR3:

station	plane	volumes
MB1, MB1'	1, 5	'RP1W', 'RP5W'
MB2, MB2'	2, 6	'RP2W', 'RP6W'
MB3	3	'RP3W'
MB4	4	'RP4W', 'RP7W', 'RP8W'

station	plane	volumes
ME1	1	'RW11', 'RW12', 'RW13'
ME2	2	'RW21', 'RW22'
ME3	3	'RW31', 'RW32'
ME4	4	'RW41', 'RW42'

3. Barrel wheel number IWHEEL is defined according to the following table:

NAMES(NLEVEL-4)	'MBXX'	'MBXX'	'MCXX'	'MBXX'	'MBXX'
NUMBER(NLEVEL-4)	4	3	1	2	1
IWHEEL	1	2	3	4	5

Digitised hits are stored in standard Geant DIGI banks.

- SET identifiers are 'MRBX' and 'MRFX'.
- DET identifiers are identical to the sensitive volume names listed above.

Definition of the banks is contained in files mb.tz and mf.tz:

```
:detd  :MRBX  :RP*W  10    #. no. of digitization elements for barrel RPCs
   :ROLL      6            #. roll number
   :PLAN      3            #. physical plane number
   :STRP     12            #. physical strip number
   :TOF      16            #. absolute time
   :ITOF      5            #. digitised time (in bx units)
   :XPHI     10            #. where (in phi) a strip was hit
   :RORZ     10            #. where (R or Z) a strip was hit
   :USR1     10            #. user defined
   :USR2     10            #. user defined
   :USR3     10            #. user defined
```

They are accessible through a call to the routine UTFDIGI, e.g.

```
    CALL UTFDIGI ('MRBX', NTDIM, NVDIM, NDMAX, LTRA, NTRA, NNUMBV,
   +              KDIGI, ISETS, IDETS, IHITS, NDIGS, IRC)
    DO I=1,NDIGS
      IROLL  = KDIGI(1,I)-30    ! roll number
      IPLANE = KDIGI(2,I)       ! physical plane number
      ISTRIP = KDIGI(3,I)       ! physical strip number
      TOF    = KDIGI(4,I)/100.  ! absolute time
      ITOF   = KDIGI(5,I)       ! digitised time (in bx units)
      XPHI   = KDIGI(6,I)/1000. ! where (in phi) a strip was hit
      RORZ   = KDIGI(7,I)       ! where (R or Z) a strip was hit
    ENDDO
```

RPC trigger simulation

Flow chart:

```
GTRIG  → ...
       → GUDIGI    → ...
       → CML1_TRG  → MRTRIG  → MRLOAD
                             → MREVENT         → MRETAPHIPT
                             → MREVENTOUT
                             → MRHFILL1
                             → MREFFIC
                             → MRCLUSTER
                             → MRSORTHITS
                             → MRDECLUSTER
                             → MRLOGHITS       → MRHFILL5
                             → MRDEFINEPACE
                             → MRMARKTOWERS
                             → MRCHECKCONES    → MRPAC
                             → MRSORTMUONS     → MRPRINTMUON
                                               → MRHFILL6
       → CMRHIT    → ...
```

Output of the algorithm is a list of muons with their positions and p_t estimated by the trigger logic. Is is stored in the MUON bank (see Sec. 8.1.5). It can be used as an input for the Global Muon Trigger simulation.

8.1.4 Control cards

The following FF cards control the MRPC simulation:

`SETS 'CMSE' 0 'MRFX' 1 'MRBX' 1`	activate forward and barrel RPC detectors
`DIGI 'CMSE' 0 'MRFX' 1 'MRBX' 1`	switch on forward and barrel RPC digitisation
`TRGP 'MTRI' 1 'RPCT' 1`	enable RPC trigger simulation
`MRPC 1 0 0 0.98 1.9 1 1`	control the RPC trigger algorithm

The syntax of the MRPC card is the following.

```
MRPC  MRPC_ACTION   MRDEBUG   MRHBOOK   REFFI   RCLUST   LDECLUST   KVETO

MRPC_ACTION /integer, default 0/
  0  - mrpc swithed off (L_RPC_TRIG=.false)
  1  - get hits from geant DIGI banks, tries to reconstruct muons.
       This is the usual way to run MRPC
  2  - instead from Geant read data from file within an internal loop
  3  - instead of reconstruction saves data to file
       Values of 2 and 3 allows to read/write date to dedicated MRPC files.

MRDEBUG /integer, default 0/
  Note that debugging action is taken in coincidence with IDEBUG (Geant GCFLAG)
  level 0      - no debug, only warnings and errors reported
  level 1<i<10 - increasing levels, up to thousands of lines per event
  level i>10   - more serious debug for given routine +1..10 debug
  level i<-10  - more serious debug for given routine
  Available values: 1,3,4,5,6,7,8,10,-11,11; the most useful: -11,5,7
  Level 5 prints eta-phi map of muons for each event
```

```
MRHBOOK /integer, default 0/
  Initialization of HBOOK fistograms for RPC
  0 - no histograming
  1 - booking of histograms in M_INITH_RPC and filling in MRHFILL*

REFFI /real, default 0.98/
  Defines efficiency of chambers

RCLUST /real, default 1.9/
  Defines average cluster size in cm

LDECLUST /integer, default 1/
   Declustrisation options (for experts only)
   0 - no declustering
   1 - N-2 algorithm

KVETO /integer, default 1/
   vetoing option (for experts only)
   0 - vetoed don't veto
   1 - vetoed do veto (eta-wise)
```

The debugging level 5 is recommended for the first trial with interactive CMSIM. Single muons can be send through the detector using command TRIG. The $\eta - \phi$ map of trigger segmnents is plotted for each event. In order to display the map of the segments properly your window must be set at least 166 characters wide. At the output empty segments are indicated by dots. Selected muon is marked by "+". Rejected candidates are marked by "−". Segments vetoed by the selected muon are indicated by "0".

8.1.5 Trigger banks

Trigger banks starts from the LRPCT link. The MRDH bank contains digitized hits reformated to facilitate trigger simulation. The MUON bank contains final result — list of muon candidates. Other banks are used to store data for intermediate simulation steps and they are of no interest for end users.

The banks are accessible in the following way.

```
#include "mrpc/rpcdes/mrclink.inc"
#include "cmsi/cmcdes/cmstree.inc"
#include "geant321/geant321/gcbank.inc"

      LRPCT = LQ(LZMTRI-LORPCT)
      LMRDH = LQ(LRPCT-LOMRDH)
      ...
      LMUON = LQ(LRPCT-LOMUON)
```

They have the following format:

```
LRPCT - link to RPCT bank (TOP bank for RPC)
DATA: none (structural links only)

MRDH - keeps DIGItised hits information, created in RPCT with offset LOMRDH
DATA: IQ(L+1) <-> IROLL    roll number
      IQ(L+2) <-> IPLANE   physical plane number
      IQ(L+3) <-> ISTRIP   absolute strip number (without any OR)
       Q(L+4) <-> TOF      absolute time
      IQ(L+5) <-> ITOF     digitised time (in bx units)
       Q(L+6) <-> XPHI     where (in phi) a strip was hit
       Q(L+7) <-> RORZ     where (R or Z) a strip was hit
```

```
LVET - used to select at most one muon per segment , discard higher "ORs" ,
       created in RPCT with offset LOLVET
DATA: IQ(L+1) <-> LVETO 1 (TRUE) or 0 (FALSE)
               When it is equal 1 muon was not processed
               Initially for all muons equal to 1
      IQ(L+2) <-> LSKIP 1 (TRUE) or 0 (FALSE)
               Shows if muon should be dropped
               Initially for all muons equal to 0

PTMU - used during veto algorithm to store pt of the muon
       (for muons with quality bit 1)
       or pt-1000 GeV (for muons with quality bit 0)
       created in RPCT with offset LOPTMU
DATA: IQ(L+1) <-> pt of the muon with IQ=1 or pt-1000 for the muon with IQ=0

MREV - event number info, created in RPCT with offset LOMREV
DATA: IQ(L+1) <-> IDRUN
      IQ(L+2) <-> IEVENT

MRVK - event vertex info, created in RPCT with offset LOMRVK
DATA:  Q(L+1) <-> PT
       Q(L+2) <-> ETA
       Q(L+3) <-> PHI
       Q(L+4) <-> VERTMR(1)
       Q(L+5) <-> VERTMR(2)
       Q(L+6) <-> VERTMR(3)

MRLH - keeps LOGICAL hits information, created in RPCT with offset LOMRLH
DATA: IQ(L+1) <-> IDHIT (idn of a bank in MRDH)
      IQ(L+2) <-> ILOW
      IQ(L+3) <-> ITOW
      IQ(L+4) <-> ISEG
      IQ(L+5) <-> ILOGP
      IQ(L+6) <-> NOR
      IQ(L+7) <-> ISTRIP_NOR

PAC - keeps information about PAC touched, created in RPCT with offset LOPAC
DATA: IQ(L+1) <-> ILOW
      IQ(L+2) <-> ITOW
      IQ(L+3) <-> ISEG
      IQ(L+4) <-> NOR
LGP1,LGP2,LGP3,LGP4 - lighted strips in PAC, created in PAC, offsets LOLGPx
DATA: IQ(L+1) <-> ISOR  (strip ORed with NOR)

MUON - reconstructed muon, created in RPCT, offset LOMUON
DATA: IQ(L+LO_ILOW)     = ILOW     muon found by low_pt (1) or high_pt (0) algorithm
      IQ(L+LO_ITOW)     = ITOW     tower number
      IQ(L+LO_ISEG)     = ISEG     segment number
      IQ(L+LO_nOR)      = nOR      OR=1,2,4,8
      IQ(L+LO_IPATNUM)  = IPATNUM  pattern number in the list of valid pattrerns
      IQ(L+LO_IQUALITY) = IQUALITY quality bit: 0-> 3 planes matched;
                                                1-> 4 planes matched
      IQ(L+LO_ICHARGEN) = ICHARGEN charge reconstructed (-1/1)
       Q(L+LO_PT)       = PT       reconstructed pt
```

8.1.6 Parametrisations

Directory mrpc/rpcpar contains functions providing parametrisation of the RPC trigger acceptance and efficiency. They are described in detail in CMS TN-1996/104.