Study of a new design of a GEM-based technology detector for the CMS experiment

Instr17: Instrumentation for Colliding Beam Physics

Budker Institute of Nuclear Physics
Novosibirsk State University Novosibirsk (Russian Federation)

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on behalf of the CMS Muon Group

Outline

- Motivation
  - The CMS Muon System
  - ME0 chamber for the Muon System Upgrade
- The Back-to-Back GEM detector
- Detector performance
  - Gain
  - Time Resolution
  - Efficiency

Motivation

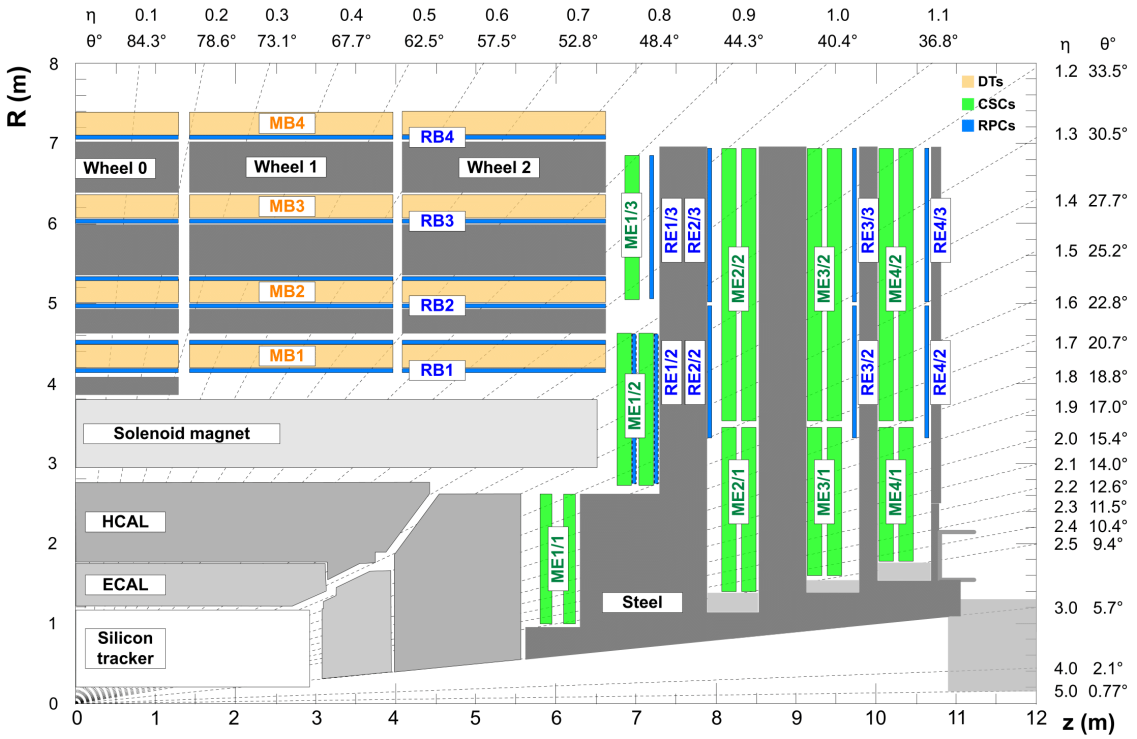
The CMS Muon System

3 Technologies:

- Drift Tubes (DTs)
- Cathode Strip Chambers (CSCs)
- Resistive Plate Chambers (RPCs)

Status:

- Complementary technologies available up to $|\eta| > 1.6$
- Region $1.6 < |\eta| < 2.2$ currently covered only by CSCs
- The muon system is currently uninstrumented at $|\eta| > 2.4$

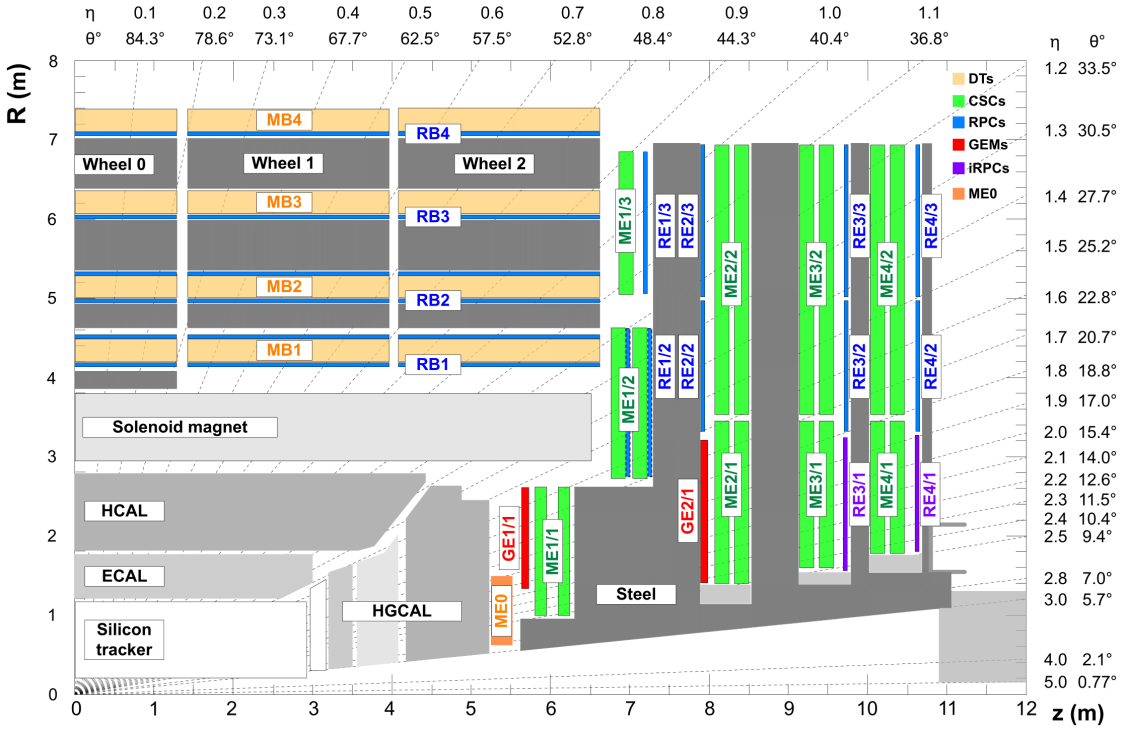


ME0 chamber for the Muon System Upgrade

One proposed upgrade is the
ME0 station
in the 2.0 < |η| < **2.8** region
(to be installed in 2024)

Goals:

- Significant **increase of the muon acceptance**
- Improved tagging of high-eta muons
- Improved muon trigger



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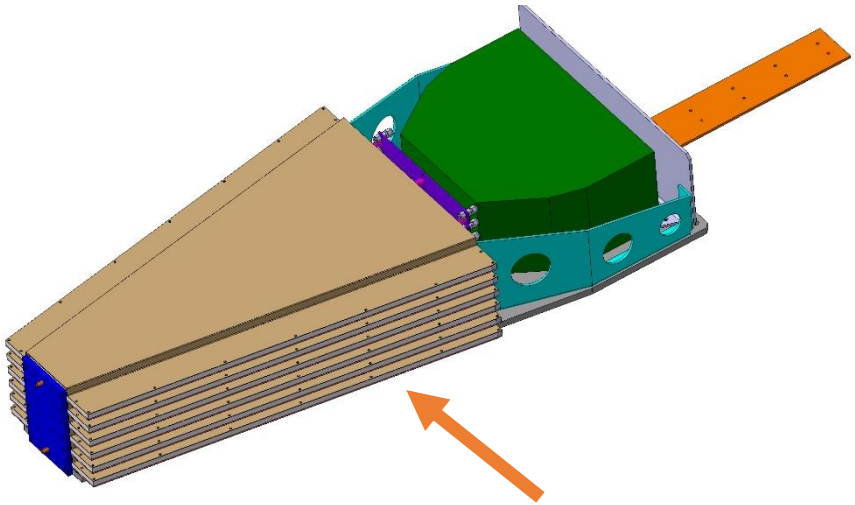
Requirements:

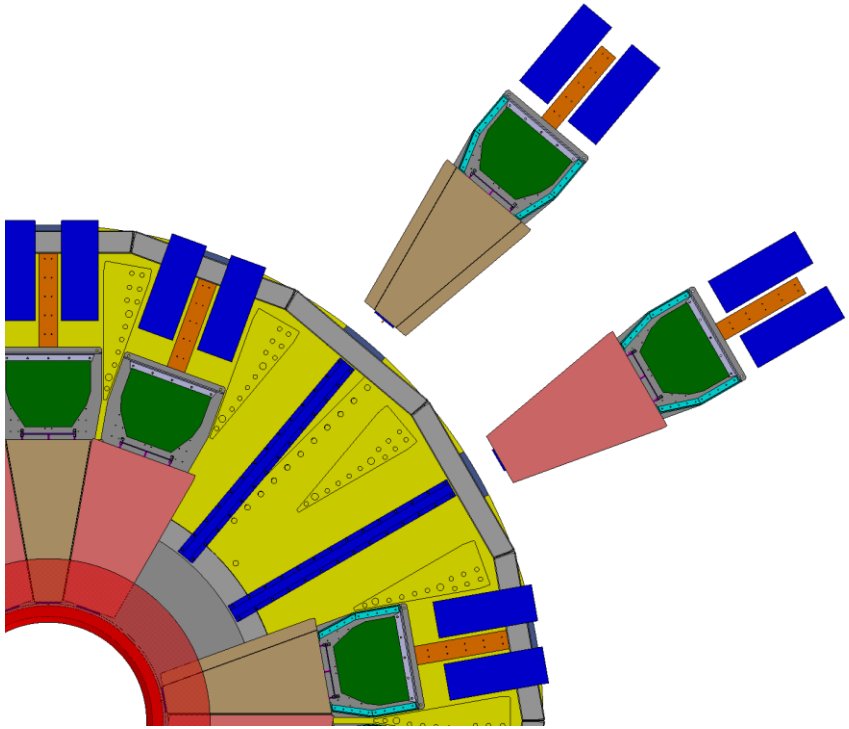
- Multilayer structure
  → small space available
  (less than 30 cm)
- High rate capability O(MHz/cm^2)
- Time resolution for triggering
- Good spatial resolution O(100 μm) for triggering and tracking

ME0 chamber for the Muon System Upgrade

Multilayer structure: to allow high efficiency in the reconstruction of the segment with at least 3 hits



Structure of 6 layered detector



Stack geometry for the ME0 station

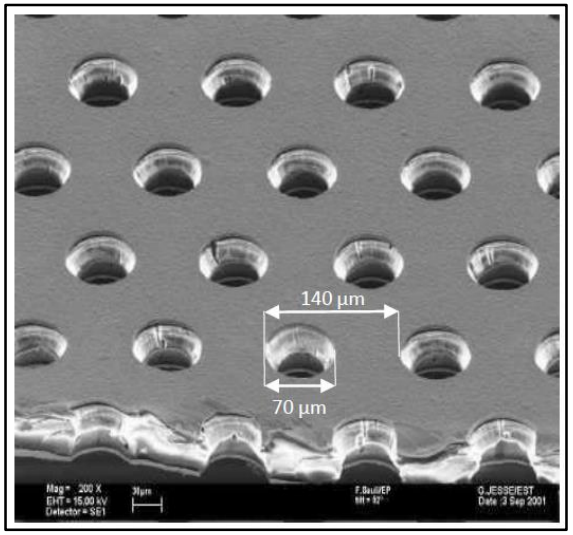
Installation of the chambers into the endcap ring.

The Gas Electron Multiplier (GEM)

Technology already chosen by CMS for the GE1/1 station

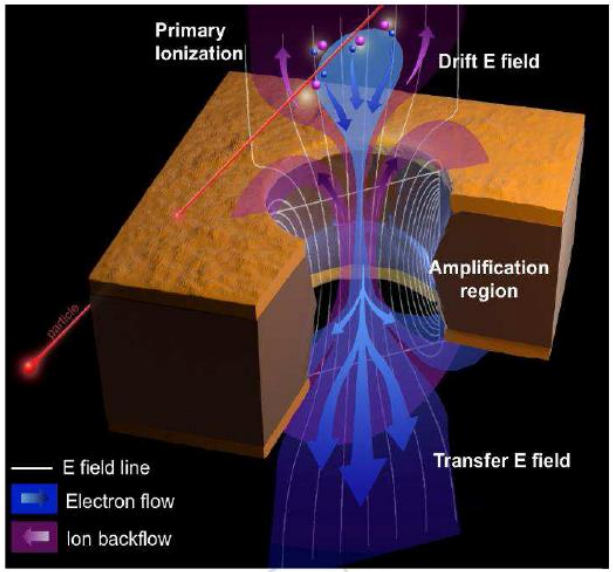
DESIGN

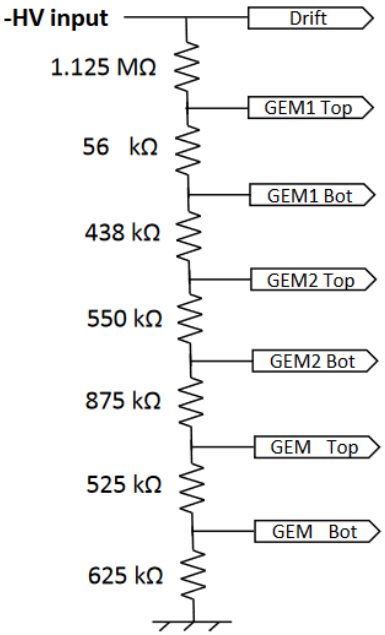
- A GEM foil is a 50 µm thick polymer foil coated with 5 µm copper on each side
- Regular (hexagonal) pattern of holes
- Biconical holes with maximum diameter of 70 µm, interspace 140 µm
- A triple-GEM is a stack of three GEM foils



OPERATION

- Potential difference applied on copper sides through a divider
- Electric field between foils → drift of charges in opposite directions
- High electric field inside holes → avalanche multiplication of electrons entering the holes
- Signal collected with appropriate electronics

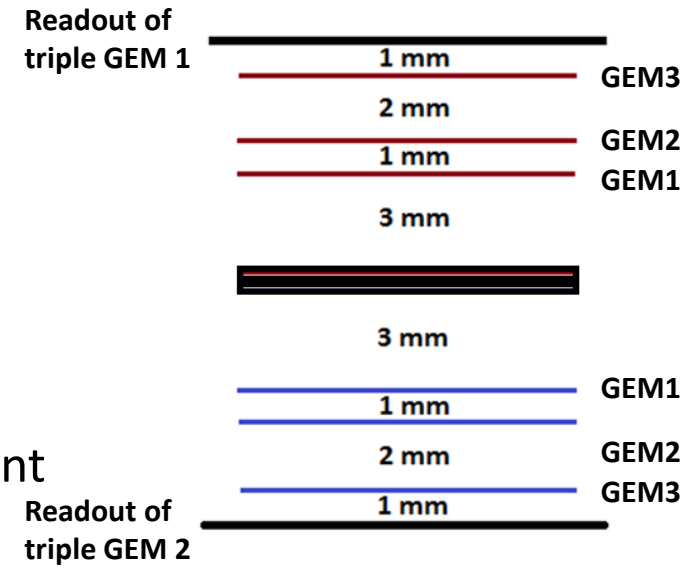


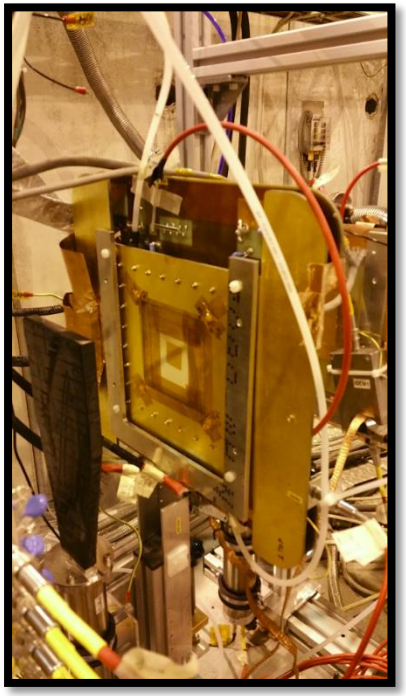


The Back-to-Back GEM detector

Compact-size multi-layered detector

- MicroPattern Gas Detectors (MPGDs) have high rate capability, good time and spatial resolution
- Challenge: make 6 layers of MPGDs fit the reduced available space!





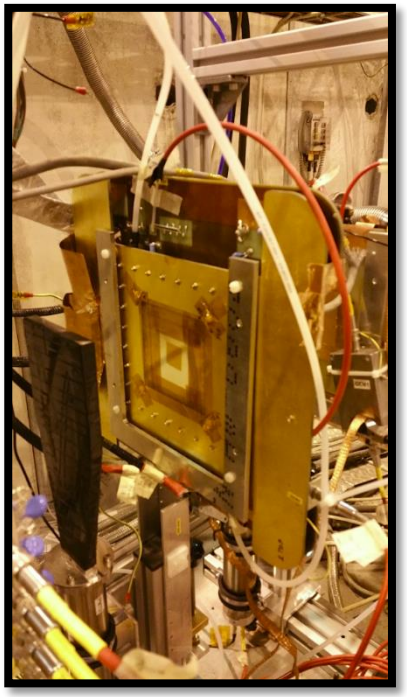
The Back-to-Back (B2B) GEM detector:

- composed of two independent triple-GEM detectors
- positioned with the anodes toward the outside
- sharing the same cathode

Prototype Details

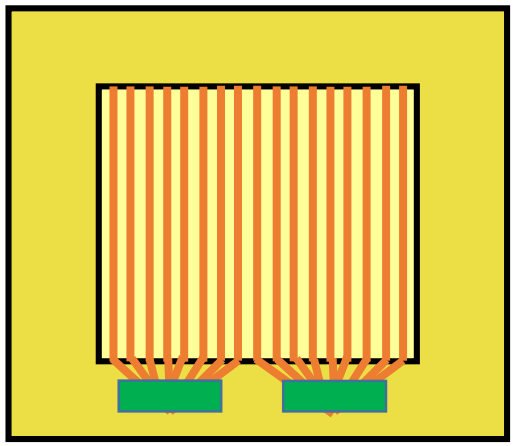
The detector is made of two back to back triple GEM detectors with

- Active area 10 x 10 cm^2 each
- The voltage is applied to each GEM detector through a divider
  (one divider for each GEM)
- Dividers are supplied in parallel by the same HV supply
- Total detector thickness: 2.64 mm
- Each GEM detector has 3/1/2/1 mm spacing
- Each GEM detector has a readout with 128 parallel strips read by VFAT2 (see backup slide) and 800 micron pitch
- One GEM has readout strips in x direction
- One GEM has readout strips in y direction

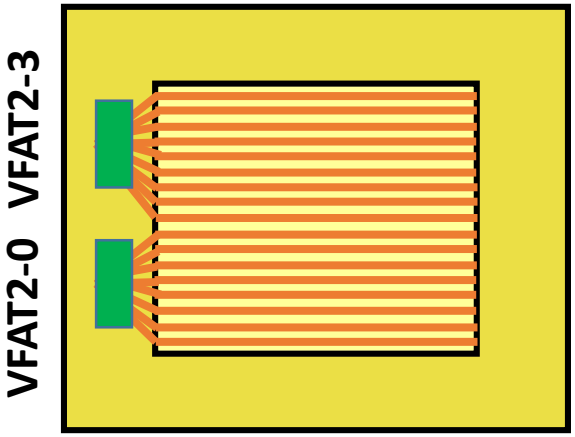


Prototype Details

Side 1
Triple GEM with X axis readout



Side 2
Triple GEM with Y axis readout



In next results on timing:

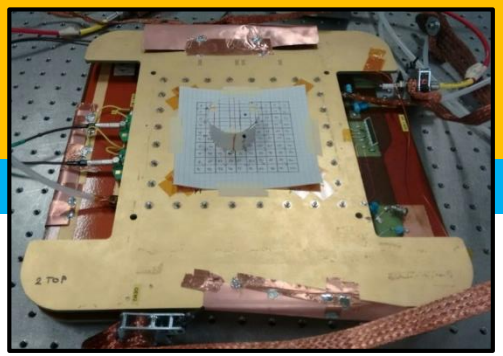
- «**VFATX**» indicates that the signal from **one GEM** (with **X axis readout**) has been used
  → **OR** of VFAT2-0 and 1
- «**VFATY**» indicates that the signal from **one GEM** (with **Y axis readout**) has been used
  → **OR** of VFAT2-2 and 3

- «**AllVFATs**» indicates that the signal from **both GEMs** has been used (signal from all 4 VFATs),
  requiring the logic condition (0&2)+(1&2)+(0&3)+(1&3)
  → signal accepted if read by one VFAT on X and one VFAT on Y axis
  → the logic condition also corresponds to a *logic AND* between the two triple GEMs

Detector performance

GAIN

Detector Rate and Gain



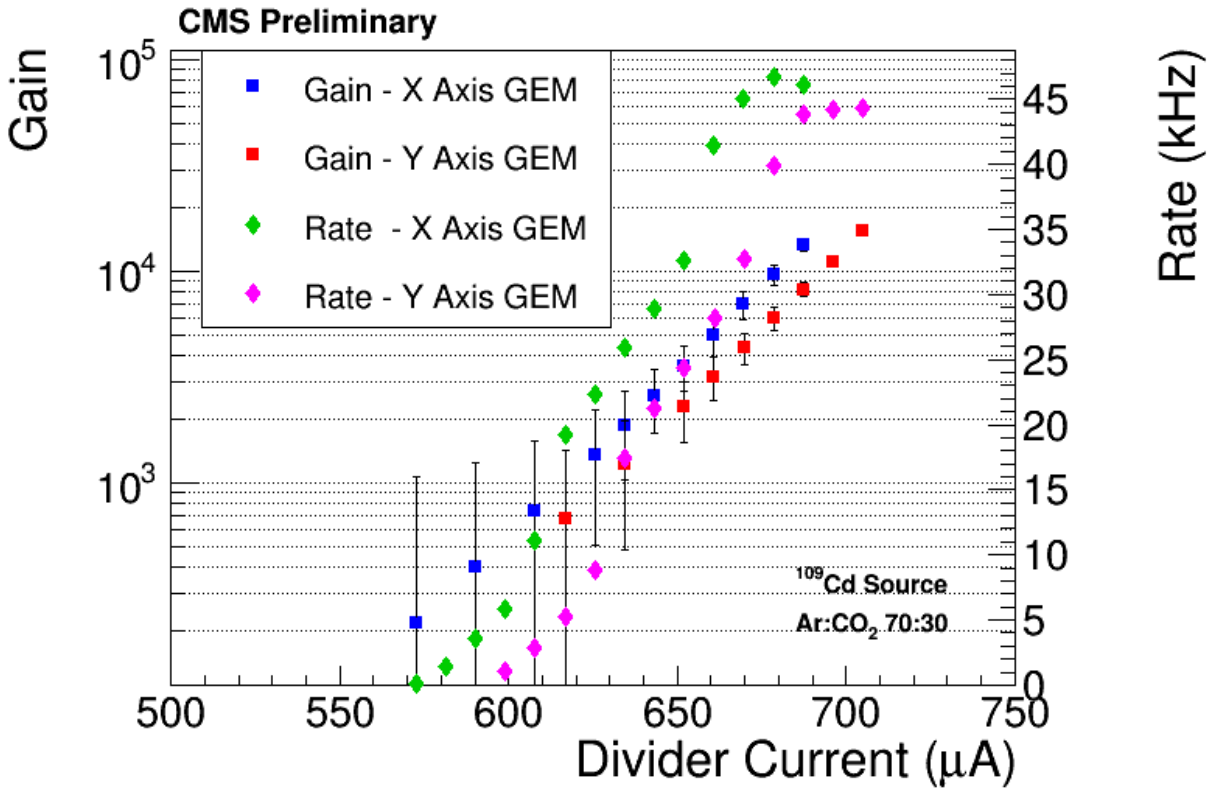
Gain up to $\sim 10^4$ (Ar:CO_2 70:30)

- The studied triple-GEM is positioned with readout up
- a ^{109}Cd source is placed on its surface (close to the triple-GEM's readout board)
- the signal is the OR of the strips

The gain is calculated as

$$G = I_{net}/(N_p q_0 R_{plateau})$$

Assuming that the ionizing radiation is due to the luminescence of the copper inside the detector.



Detector performance

TIME RESOLUTION

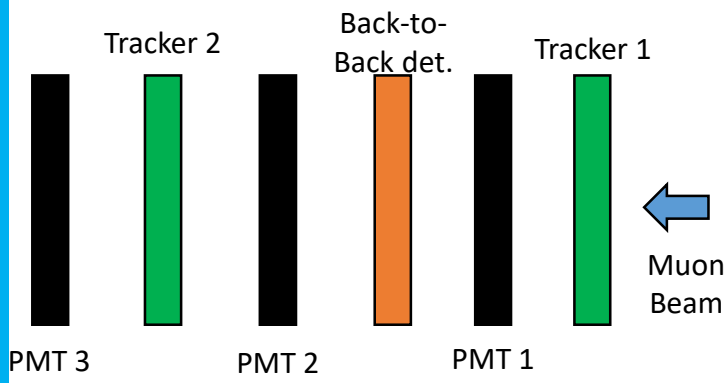
Setup for Efficiency and Timing measurements

Results with **Ar:CO_2 70:30** and **Ar:CO_2:CF_4 45:15:40** gas mixtures

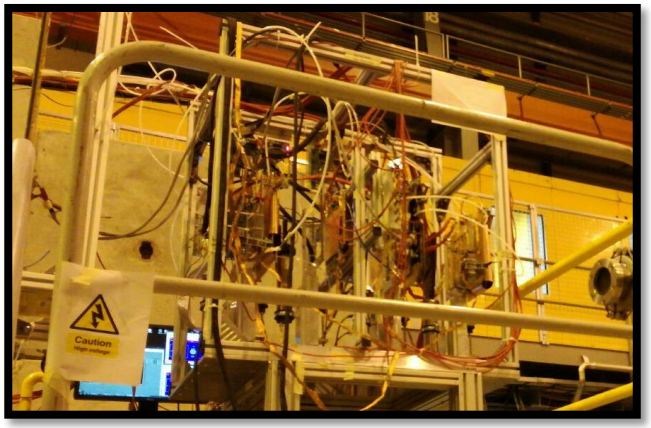
Muon Testbeam at CERN SPS

Momentum ~150 GeV/c

Intensity up to ~10^4 muons/spill



Distances not to scale



Beam Trigger

- 3 PMTs (area 10 x 10 cm^2) for beam trigger

Tracking

- 2 triple GEM detectors with 3/2/2/2 mm spacing with Ar:CO_2 70:30 gas mixture
- Each tracker has a parallel strips readout both in x and y direction
  (256 strips – 400 micron pitch)

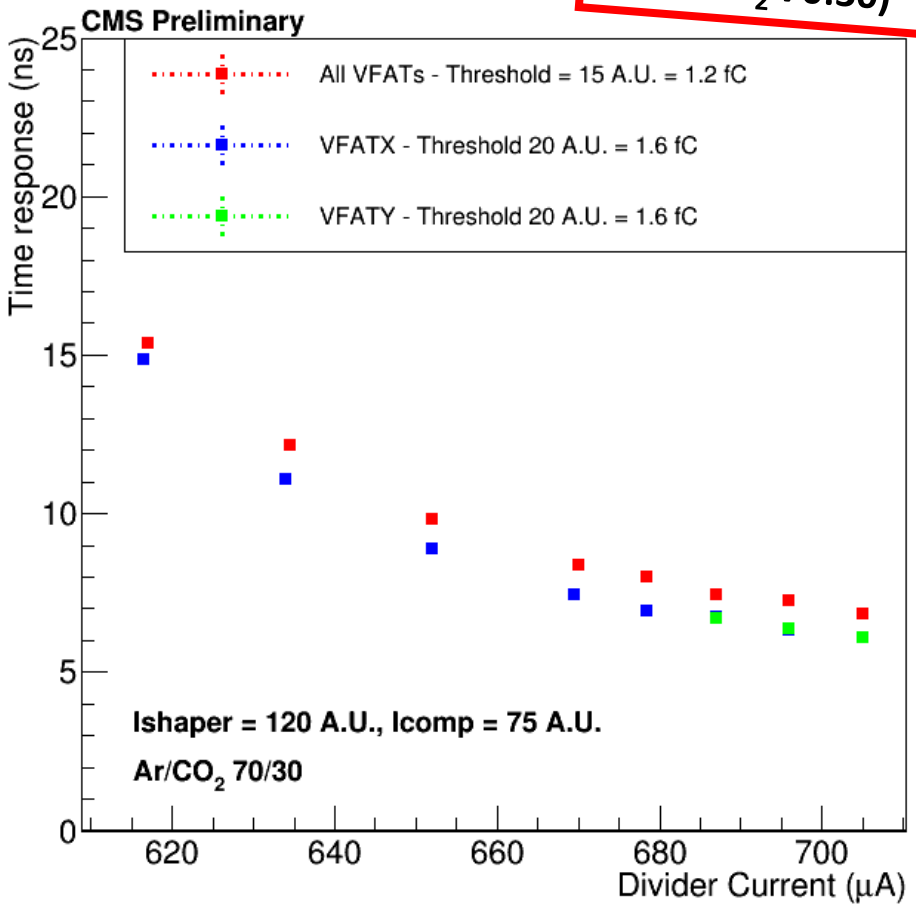
Electronics

- Signals read by VFAT2 (128 channels each)
- 4 VFATs for each detector (2 per axis)
- VFATs have 40 MHz signal sampling

Each GEM (or axis) of the B2B detector is read by 2 VFATs

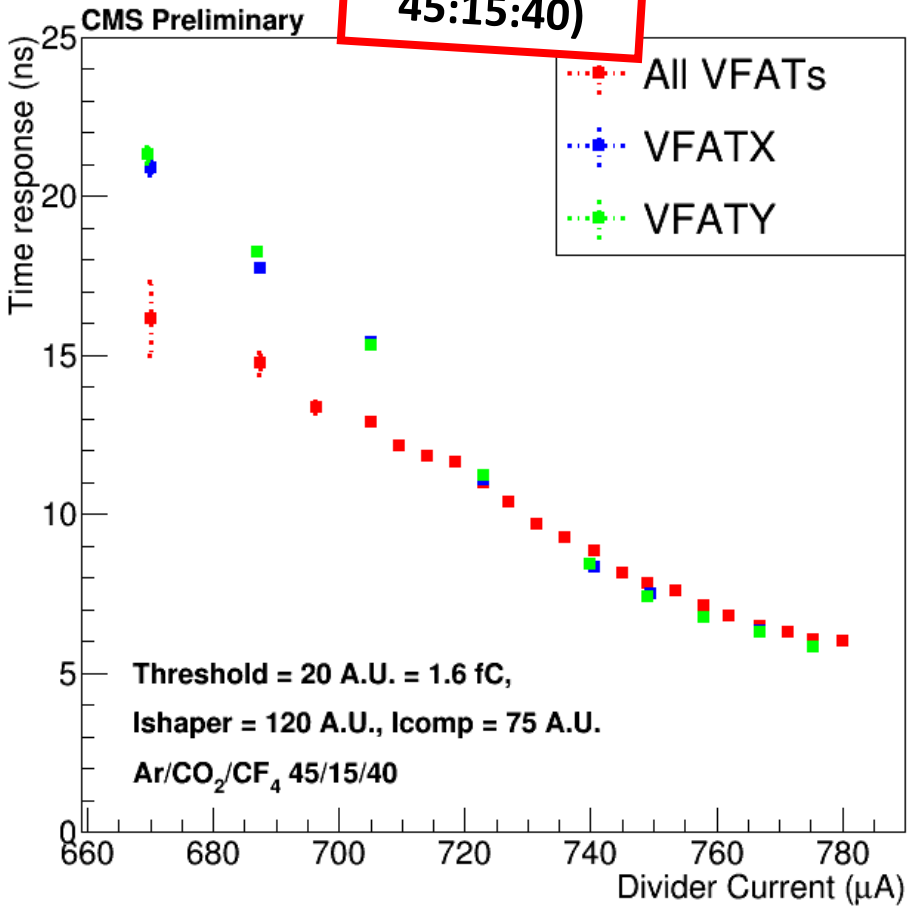
Timing Measurement

~ 7 ns
(Ar:CO_2 70:30)



The time resolution is improving at higher gain up to 6 ns at 705 uA per divider (reference value of plateau)

~ 6 ns
(Ar:CO_2:CF_4 45:15:40)



The time resolution is improving at higher gain up to 5 ns at 775.5 uA per divider (reference value of plateau)

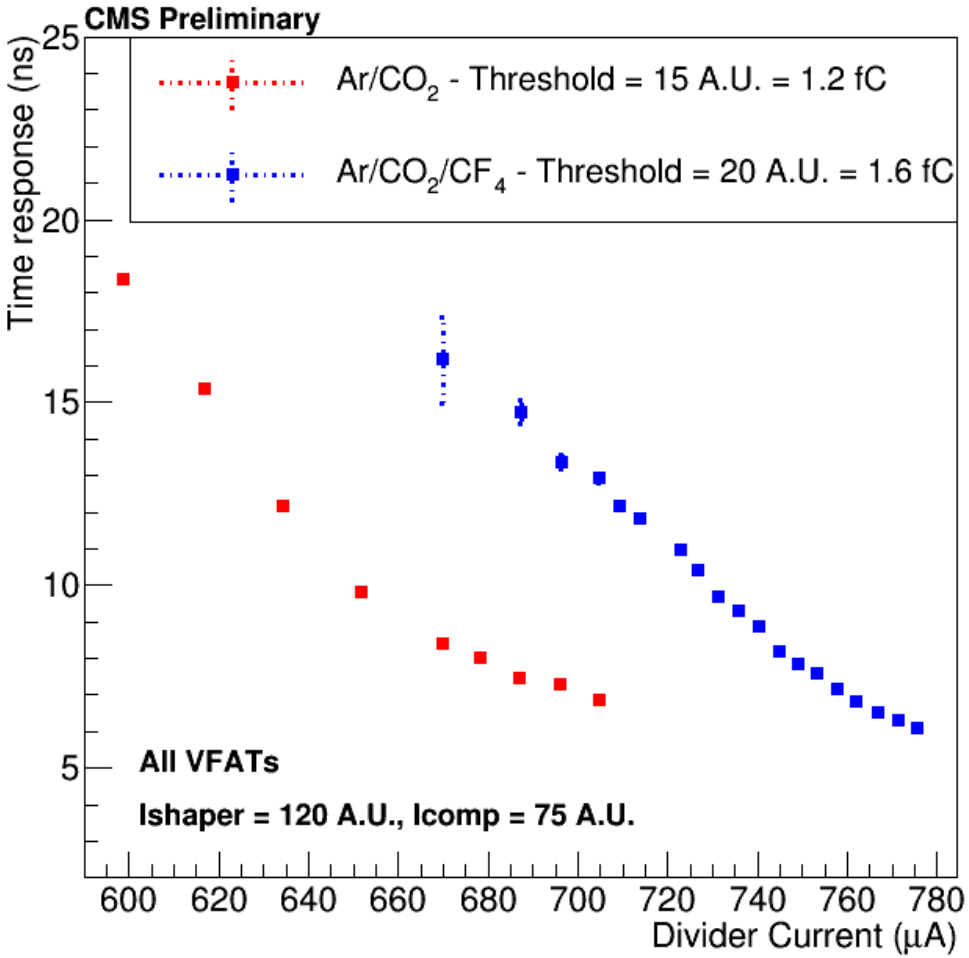
(*) Ishaper and Icomp are input parameters of the VFATs to adjust the shaping and the discrimination of the signal.
Values used in these plots have been previously tuned and optimized performing a scan in such parameters (see backup slides).

Timing Measurement

Comparison

Ar:CO_2 and Ar:CO_2:CF_4

- The best time resolution measured with Ar:CO_2:CF_4 mixture is ~ 1 ns lower than that measured with Ar:CO_2
- Results are compatible with results measured for «single» triple-GEMs in 2015 testbeam (GE1/1 prototypes)



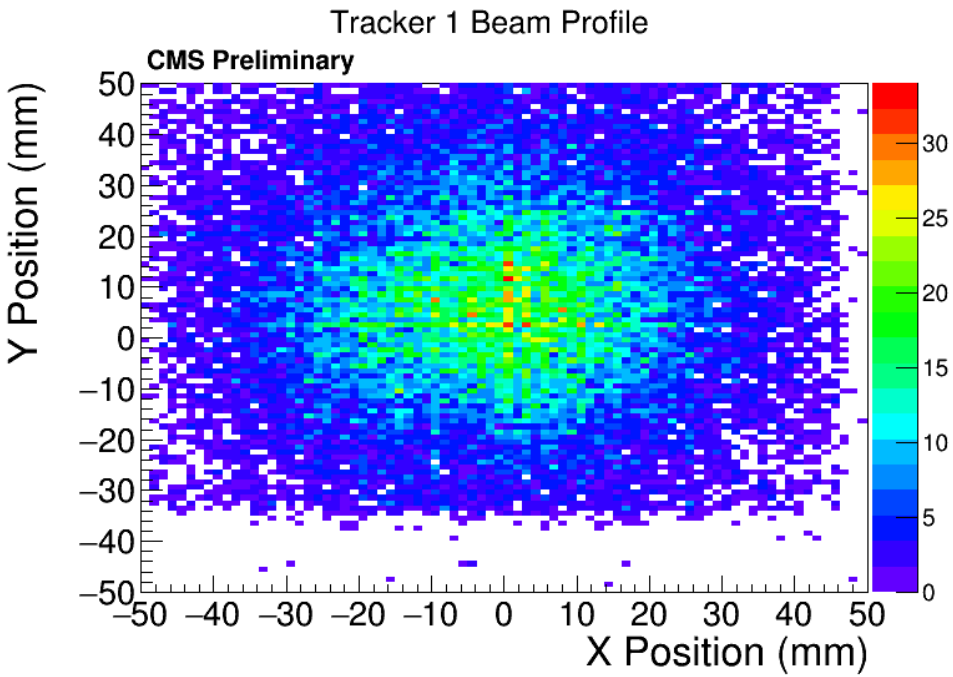
Detector performance

EFFICIENCY

Efficiency Measurement

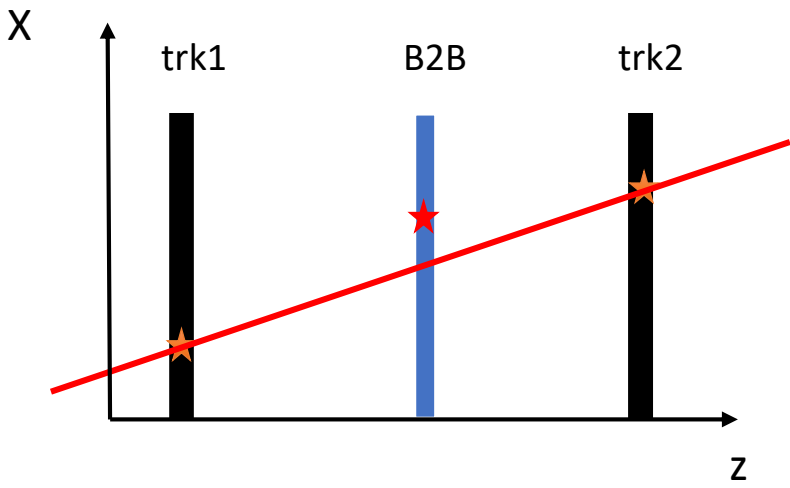
Trigger:

Coincidence of the 3 photomultipliers



To reconstruct trajectory:

- Two trackers with 10x10 cm^2 active area
- Trackers are triple GEM detectors with 2D readout (parallel strips both along x and y axis)



Efficiency Measurement

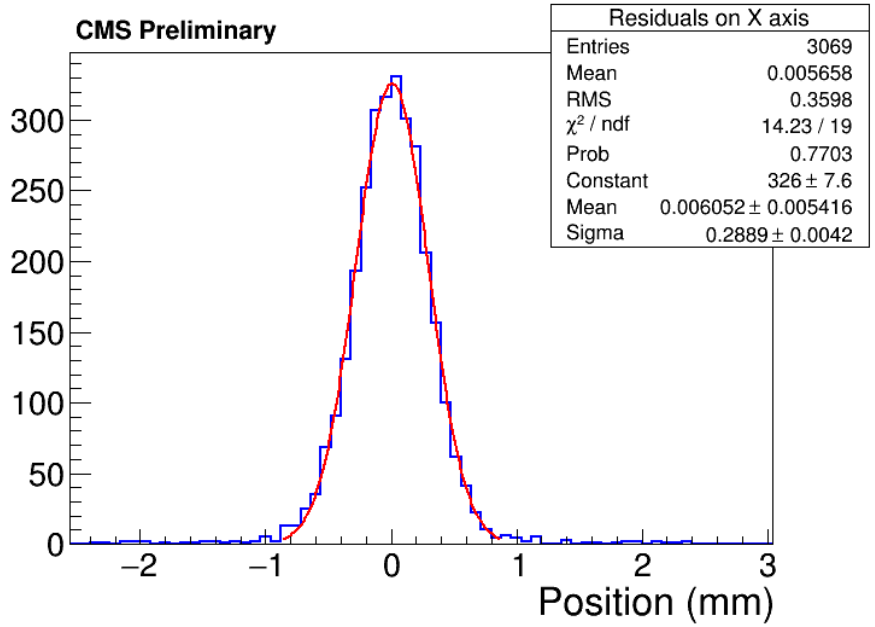
Efficiency software summary:

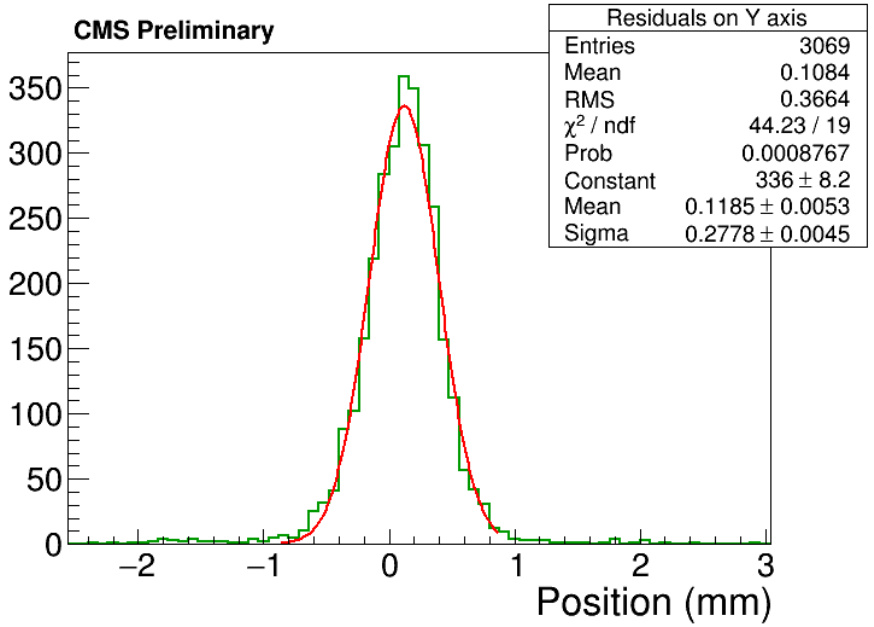
1. Software alignment of the detectors
   rotation and translation correction of hit positions, via a χ^2 minimization

Efficiency Measurement

Efficiency software summary:

1. Software alignment of the detectors
2. Determination of σ of residuals
   the maximum accepted distance of hits on Back-to-Back GEM detector from the reconstructed track is a 3σ interval
   (σ of the gaussian fit of residuals on X and Y axis)



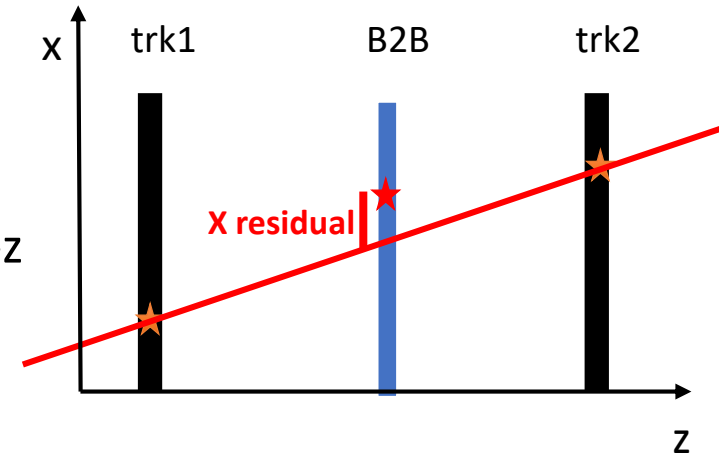


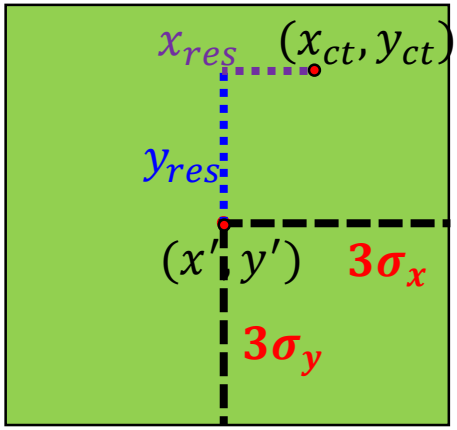
Efficiency Measurement

Efficiency software summary:

1. Software alignment of the detectors
2. Determination of σ of residuals
3. Efficiency calculation

- construct the straight line in x-z plane (and y-z plane) through the positions measured on trackers
- compute its intercept x' (and y') on the B2B detector and calculate the distance $x_{res} = |x' - x_{cl}|$ (y_{res} resp.) of the closest cluster in x direction
- for efficiency of X-axis GEM (Y-axis GEM resp.) events are accepted only if $\boldsymbol{x_{res} < 3\sigma_x}$ ($\boldsymbol{y_{res} < 3\sigma_y}$ resp.)
- For the Efficiency of AND ***both conditions*** are requested



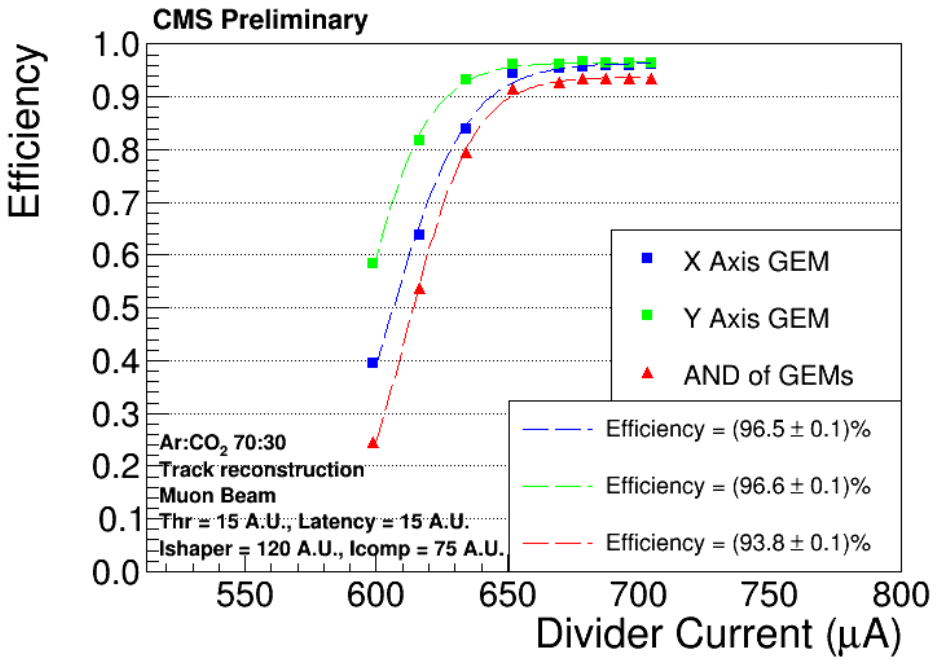


Efficiency Measurement

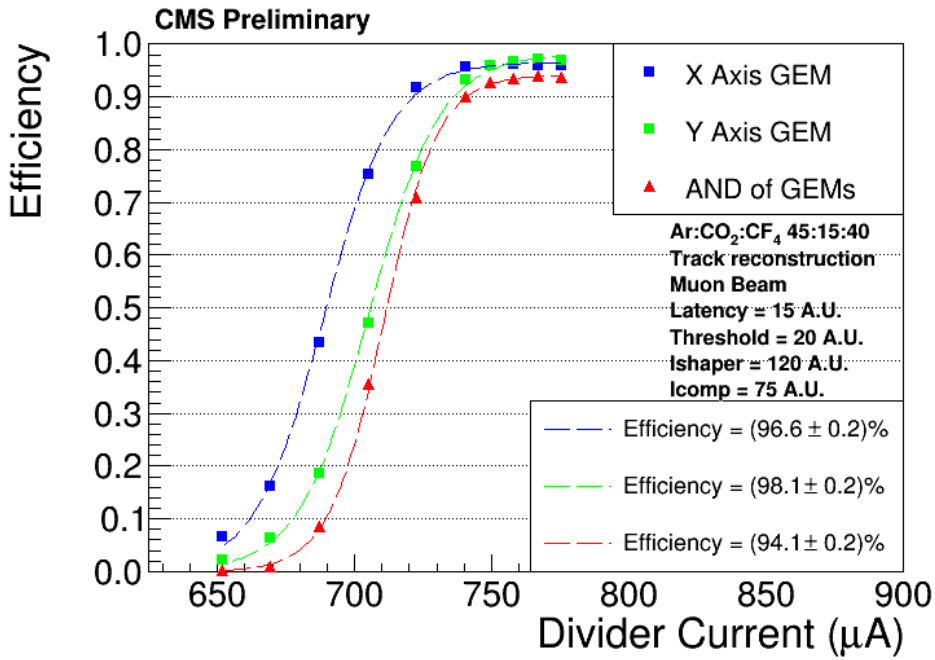
X axis GEM: 96.5%
Y axis GEM: 96.6%
from 675 µA per divider

X axis GEM: 96,6%
Y axis GEM: 98.1%
from 750 µA per divider

$Ar:CO_2$



$Ar:CO_2:CF_4$

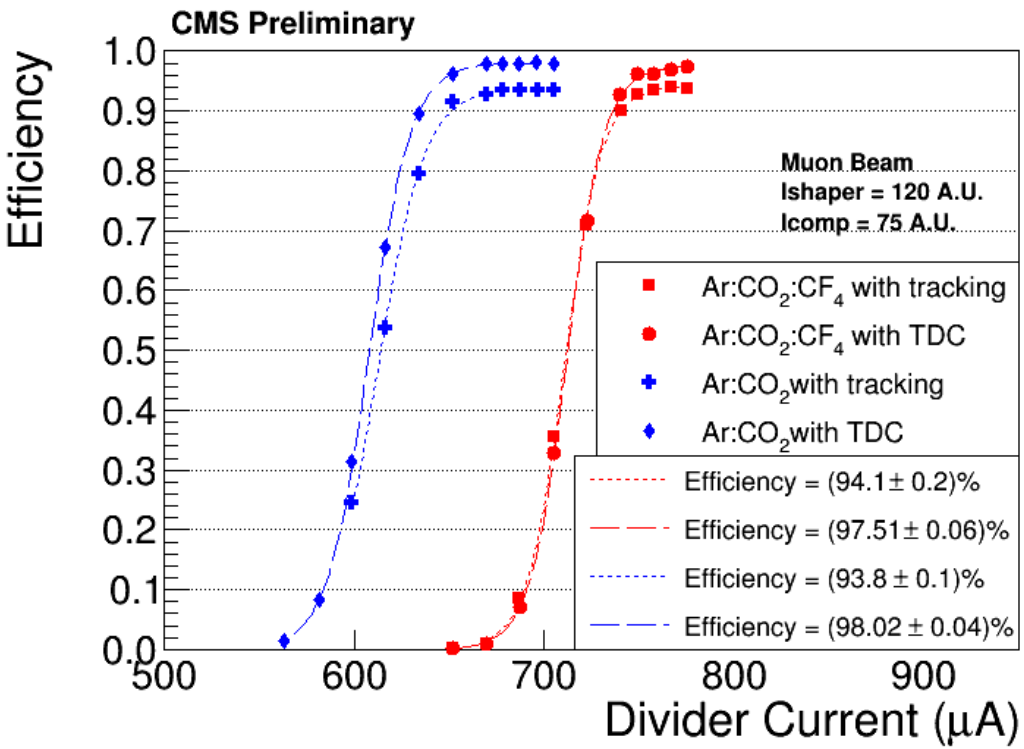


Summary

- The Back-to-Back GEM detector is under study for the upgrade of CMS muon system at high eta
  - Currently uninstrumented region
  - Small available space
  - Multi-layer structure, high rate capability, good time and spatial resolution necessary
- The detector is composed of two triple GEM detectors sharing the same cathode, with anode towards the outside
- Measured performance:
  - Gas gain up to $\sim 10^4$
  - Time resolution up to 6 ns ($Ar:CO_2:CF_4$) and 7 ns ($Ar:CO_2$)
  - Efficiency between 96.5% and 98.1% for a «single» triple GEM
- The measured performance is in good agreement with previous CMS studies on GEM detectors for GE1/1 upgrade
  [The CMS GEM Collaboration, (2015) CERN-LHCC-2015-012.]

Backup

Efficiency Measurement – with TDC

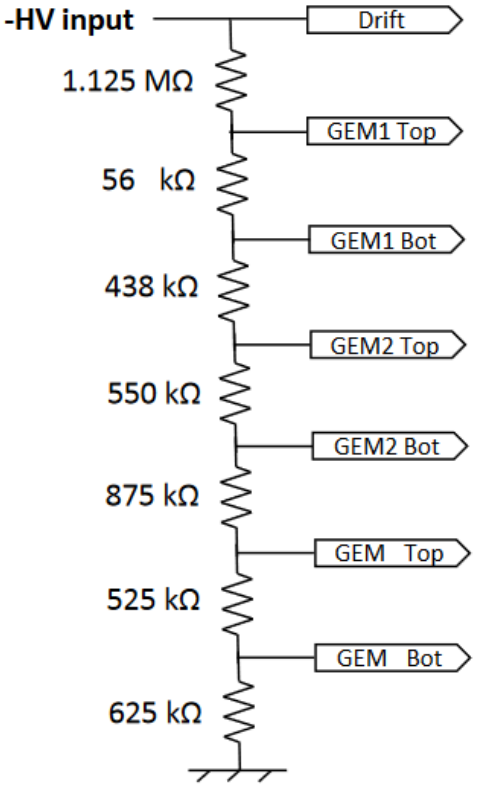


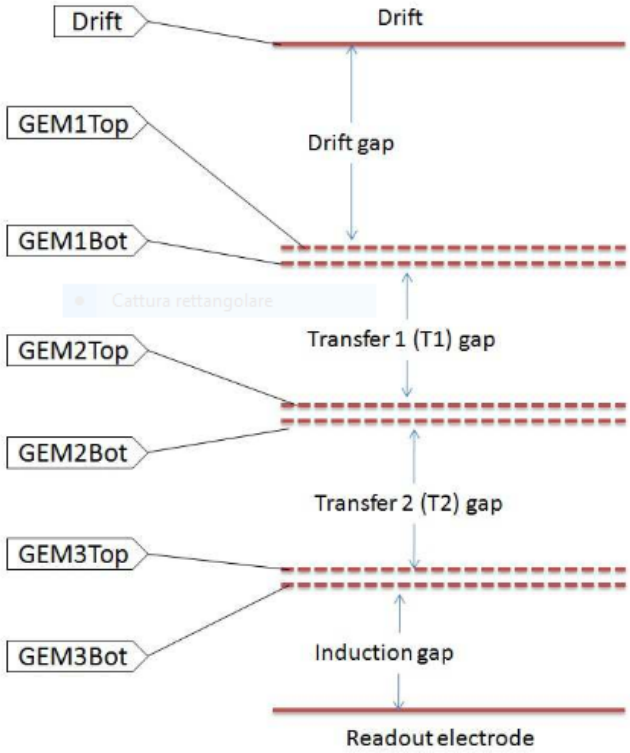
Efficiency with TDC

- Only events fulfilling the condition
  (0&2)+(1&2)+(0&3)+(1&3)
  → efficiency of the logical AND between the two triple GEMs.

Comparison: TDC and tracking

- Agreement within 3-5%
- Efficiency measurement with TDC systematically slightly higher due to a less strict noise rejection


-HV input
Drift
1.125 MΩ
GEM1 Top
56 kΩ
GEM1 Bot
438 kΩ
GEM2 Top
550 kΩ
GEM2 Bot
875 kΩ
GEM Top
525 kΩ
GEM Bot
625 kΩ


Drift
Drift
GEM1Top
Drift gap
GEM1Bot
Transfer 1 (T1) gap
GEM2Top
GEM2Bot
Transfer 2 (T2) gap
GEM3Top
GEM3Bot
Induction gap
Readout electrode

Timing measurement

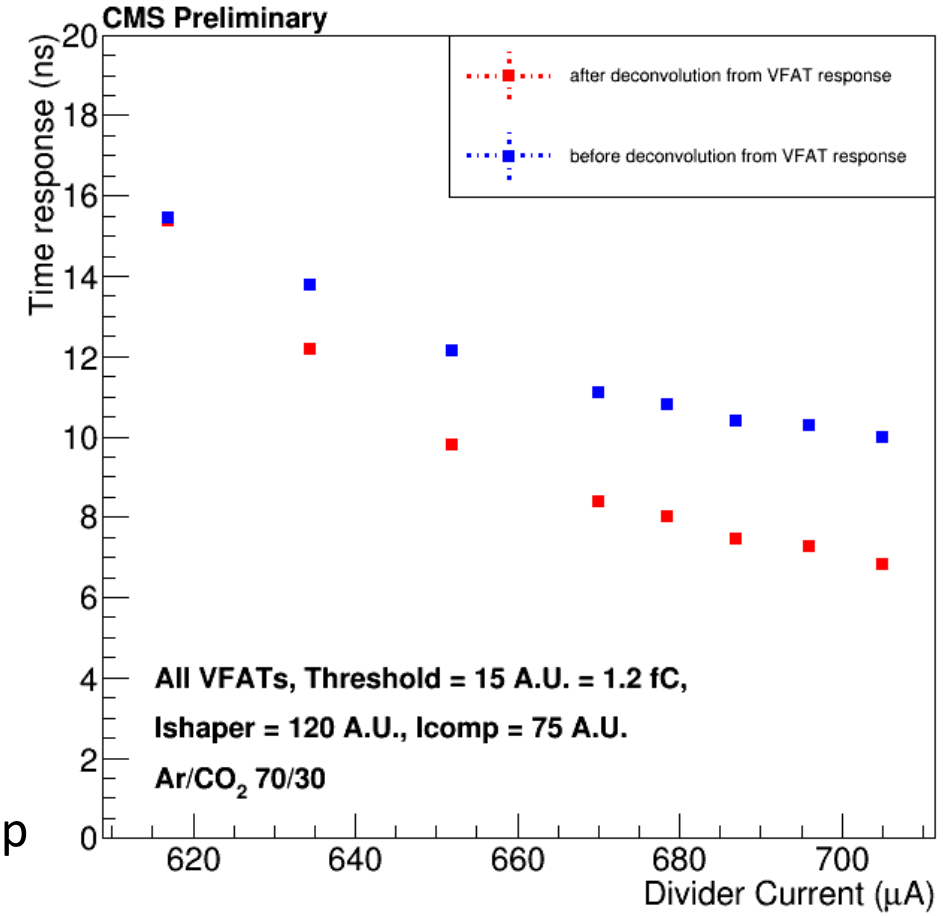
Time response w.r.t to the beam trigger is measured with a **TDC**.

Major contributions to the time response distribution of raw data :

- Time resolution of the detector
- VFATs signal sampling (40MHz)

To deconvolute from the VFAT contribution:

- fit the time distribution with the convolution of a Gaussian with a step function (25 ns width)
- the **time resolution** is the standard deviation of the Gaussian component



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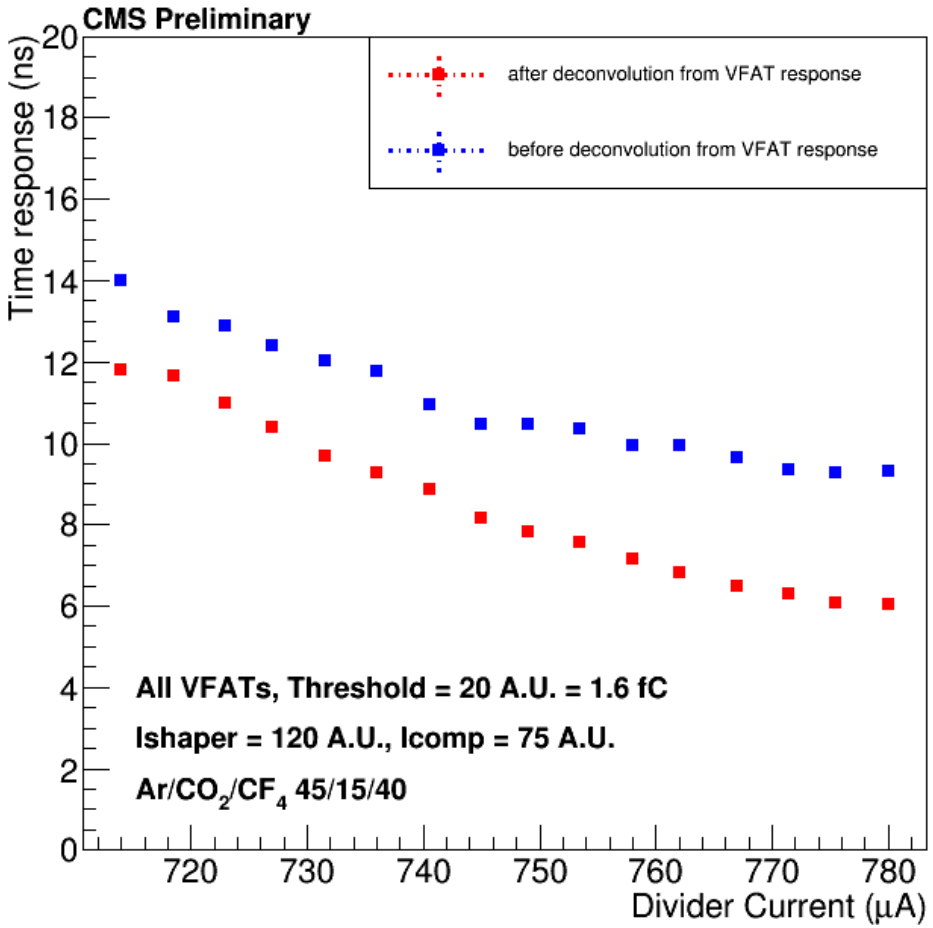
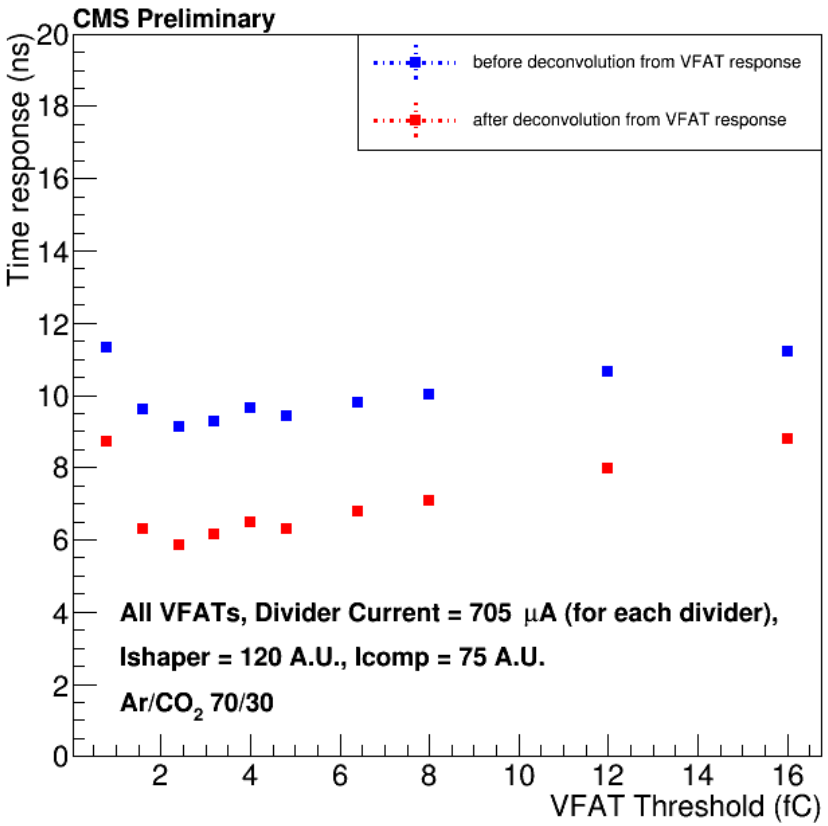
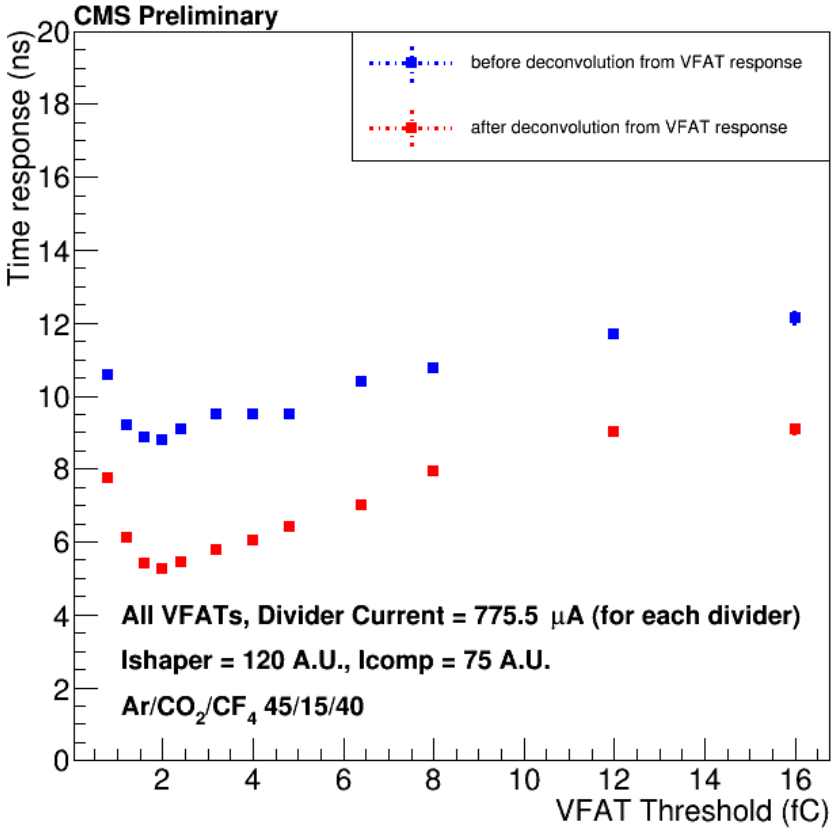


Timing measurement – vs Threshold



Best time resolution is obtained:

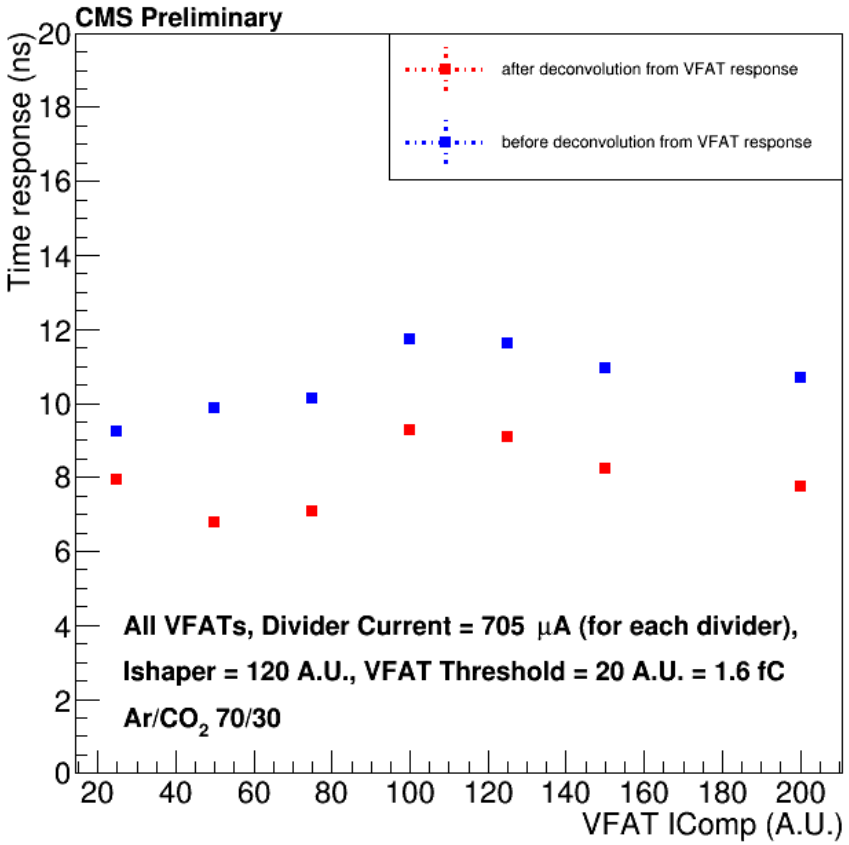
- threshold among 1.6 and 2.4 fC
- of the order of 6 ns (Reference current value: 705 μA per divider)

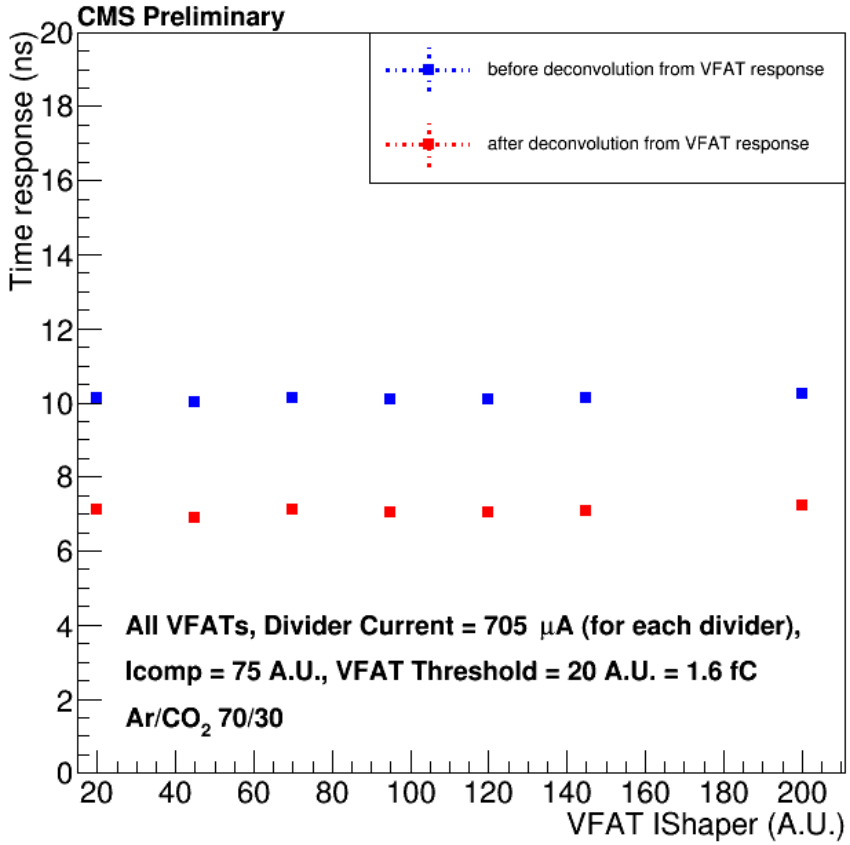


Best time resolution is obtained:

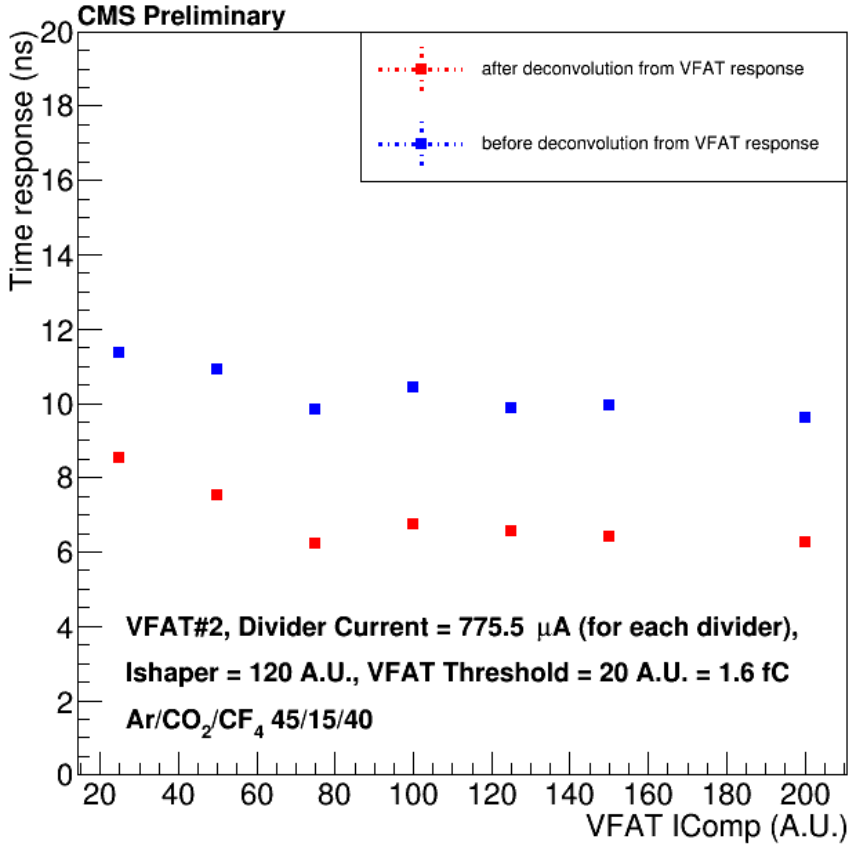
- threshold among 1.6 and 2.4 fC
- of the order of 5 ns (Reference current value: 775.5 μA per divider)

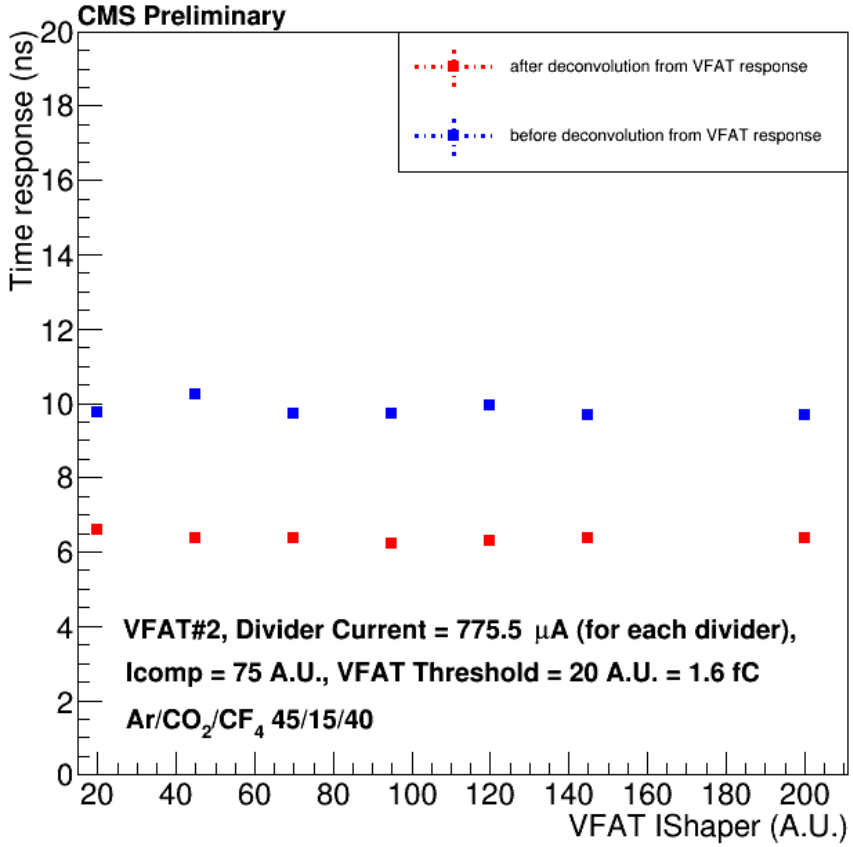
Timing Measurement – VFAT parameters





Timing Measurement – VFAT parameters





Software Alignment of detectors

The correction parameters are the ones that minimize the total chi square:

$$\chi^2_{tot} = \sum_{i=1}^{N} (\chi^2_{xi} + \chi^2_{yi})$$

where

$$\chi^2_{xi} = \sum_{i=1}^{N_{events}} \sum_{j=1}^{3} \frac{\left(x^i_{ct,j} - a^i_x x^i_j - b^i_x\right)^2}{\sigma_j^2}$$

$$\chi^2_{yi} = \sum_{i=1}^{N_{events}} \sum_{j=1}^{3} \frac{\left(y^i_{ct,j} - a^i_y x^i_j - b^i_y\right)^2}{\sigma_j^2}$$

- a^i_x, b^i_x are the coefficients of the linear fit in the zx and in the zy plane, through the experimental points measured on the 3 detectors, for each event $i = 1 \dots N_{events}$: $x = a^i_x + b^i_x z_x$ and $y = a^i_y + b^i_y z_x$
- It has been used sigma $\sigma_j = \frac{pitch}{\sqrt{12}}$
- Minimization is done using MINUIT

VFAT2

Main features:

- A 128 channel chip for charge sensitive readout of multi-channel silicon & gas particle detectors
- Trigger: Provide intelligent “FAST OR”information for the creation of a trigger.
- Tracking: Binary “hit” information for each of the 128 channels
- 40MHz signal sampling (dead time free)

Reference:

- “VFAT2: A front-end system on chip providing fast trigger information, digitized data storage and formatting for the charge sensitive readout of multi-channel silicon and gas particle detectors”, Proceedings of TWEPP Prague, Czech Republic, 3-7 September 2007, ISBN 978-92-9083-304-8, p.292
- P. Aspell, CERN

GE1/1 Station

- Installation of **triple GEM detectors** scheduled in 2019-2020 in the region $1.6<|\eta|<2.2$ of CMS muon system
- **Advanced R&D status**
- **In view of the high luminosity (Phase II):** GE1/1 will allow to keep <5 kHz trigger rate without increasing threshold on muon's momentum
  - Will be added in front of CSCs to measure the muon bending angle in magnetic field
  - Adds redundancy