MuonMonitor DAQ efficiency

MuonMonitor Workshop
10.08.2016, LSC, Canfranc

Maciej Slupecki
Department of Physics, University of Jyväskylä

Signal flow:

→ **Optical**:

- Plastic scintillator
- Optical wavelength-shifting fiber
- Avalanche Photodiode (APD)

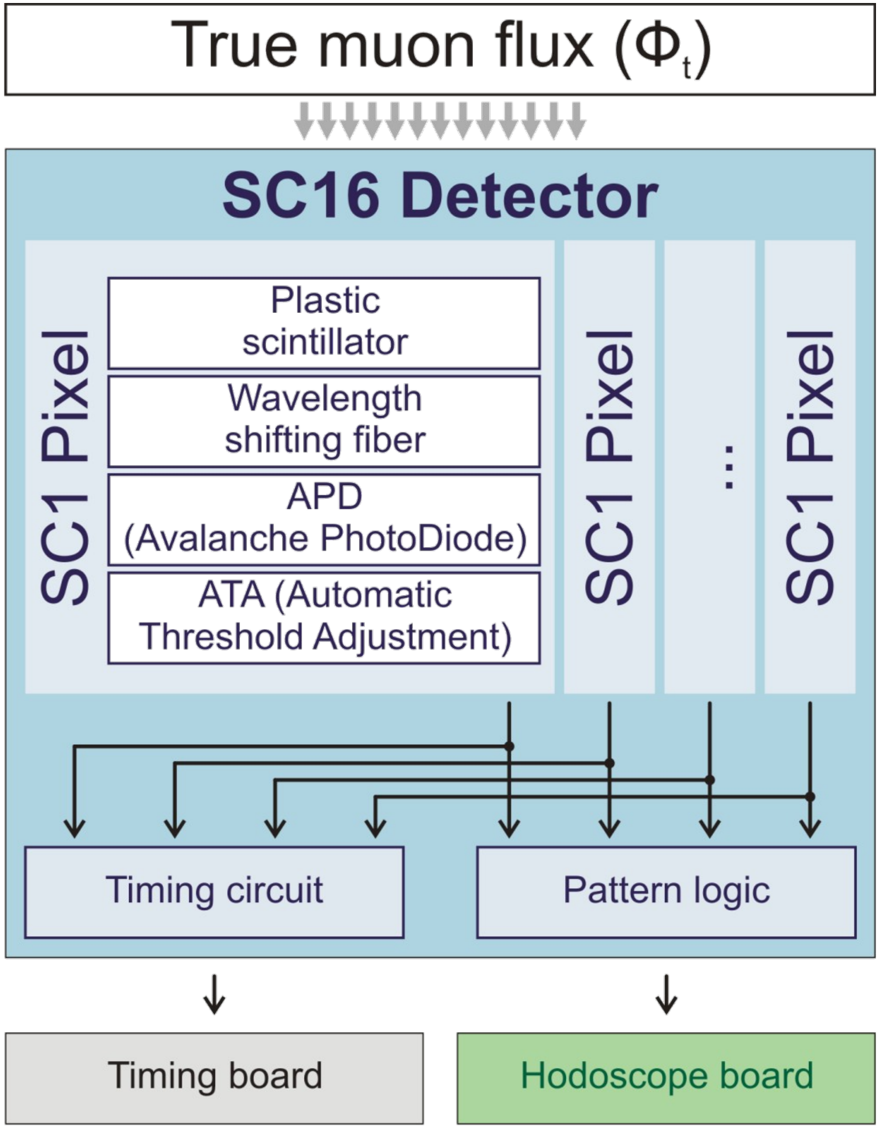
→ **Electrical:**

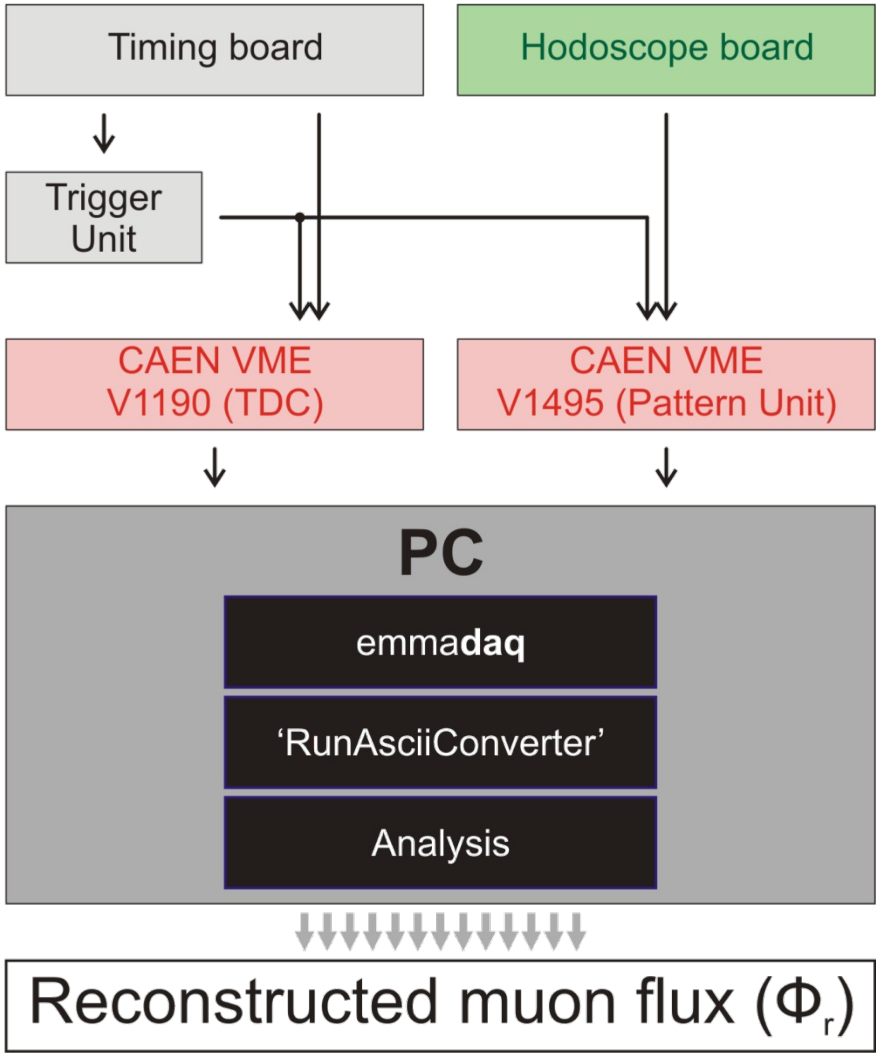
- Time circuits -> Timing Board -> TDC
- Pattern Logic -> Hodoscope Board -> Pattern Unit
- Trigger generation

→ **Logical (software)**

- DAQ
- Binary file reader
- Analysis

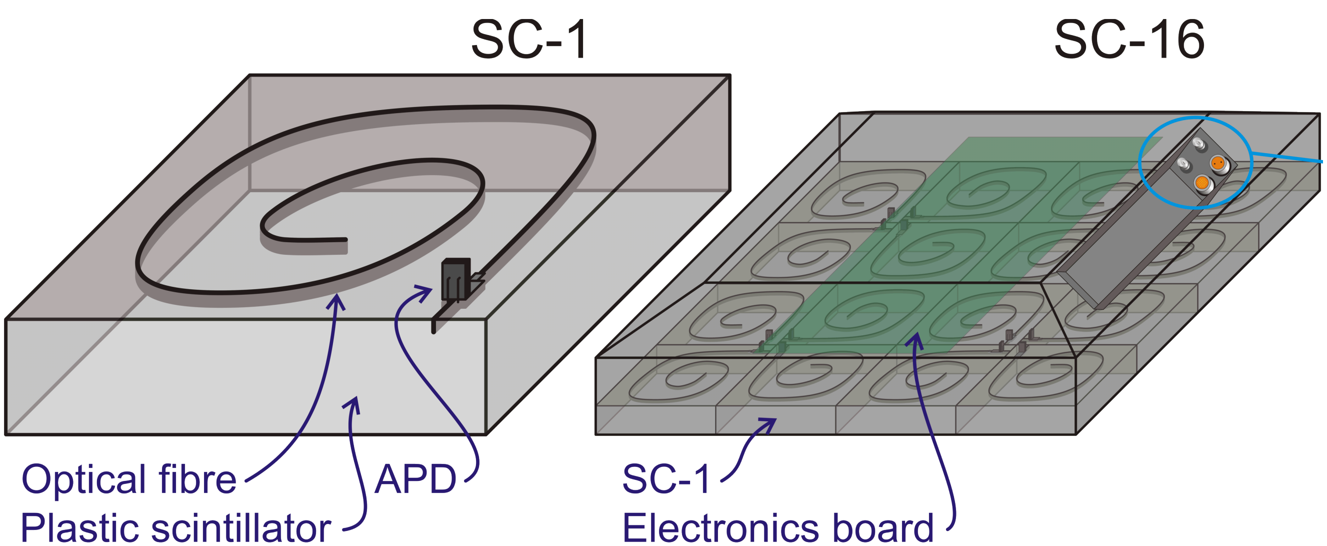
3 Signal flow 1/2

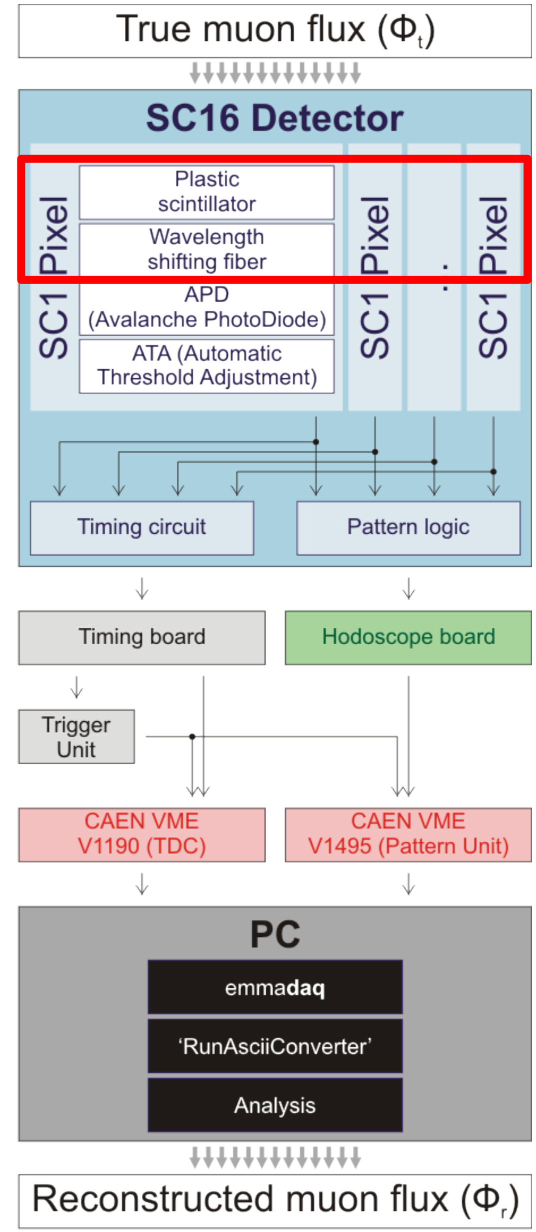



Timing board
Hodoscope board
Trigger Unit
CAEN VME V1190 (TDC)
CAEN VME V1495 (Pattern Unit)
PC
emmadaq
'RunAsciiConverter'
Analysis
Reconstructed muon flux (Φr)

Light generation in scintillator

~1e4 photons produced per MeV of deposited energy





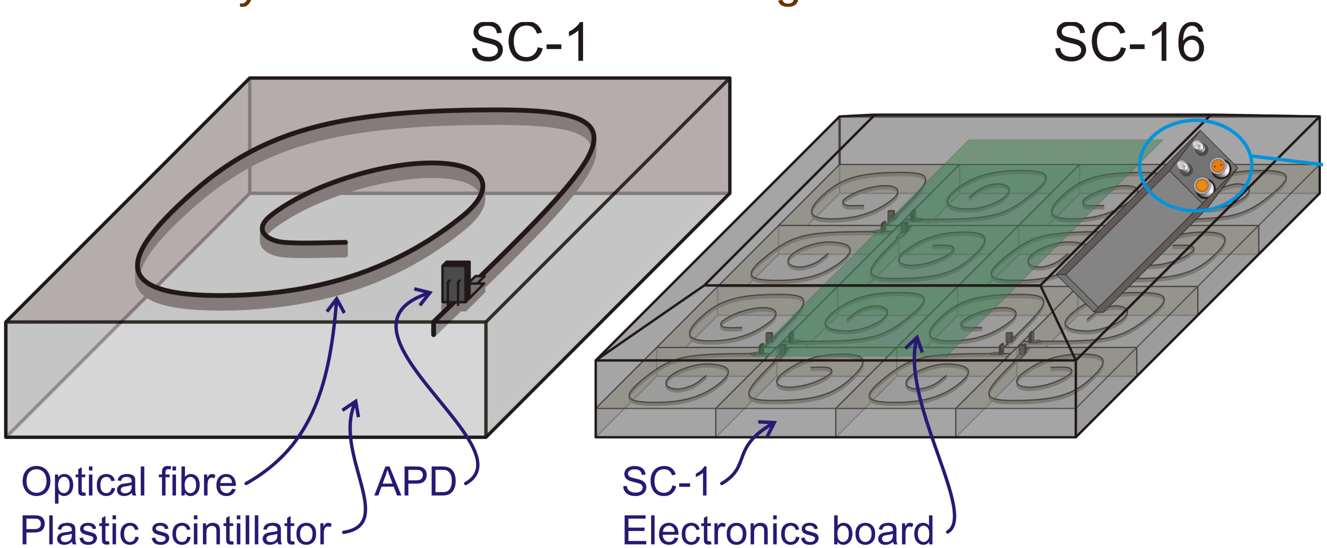
Light generation in scintillator

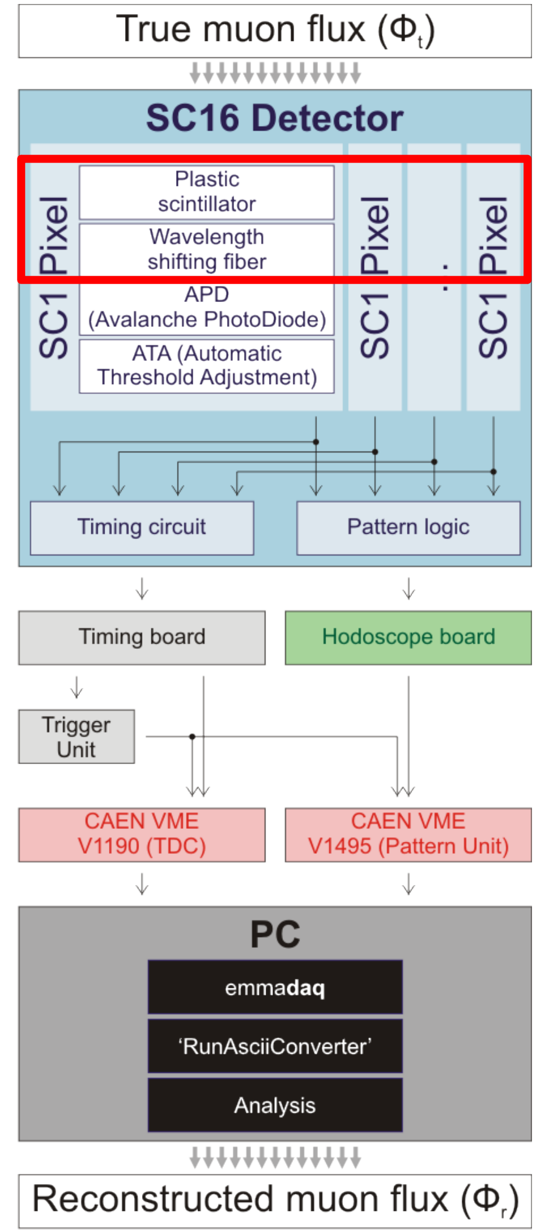
~1e4 photons produced per MeV of deposited energy

Light collection in the spiral fiber

→ small fraction of the 3e4 photons is captured by the fiber
→ wavelength shift
→ optical coupling between plastic block and fiber
→ mirror on the far end of fiber
→ polished surface of fiber next to APD

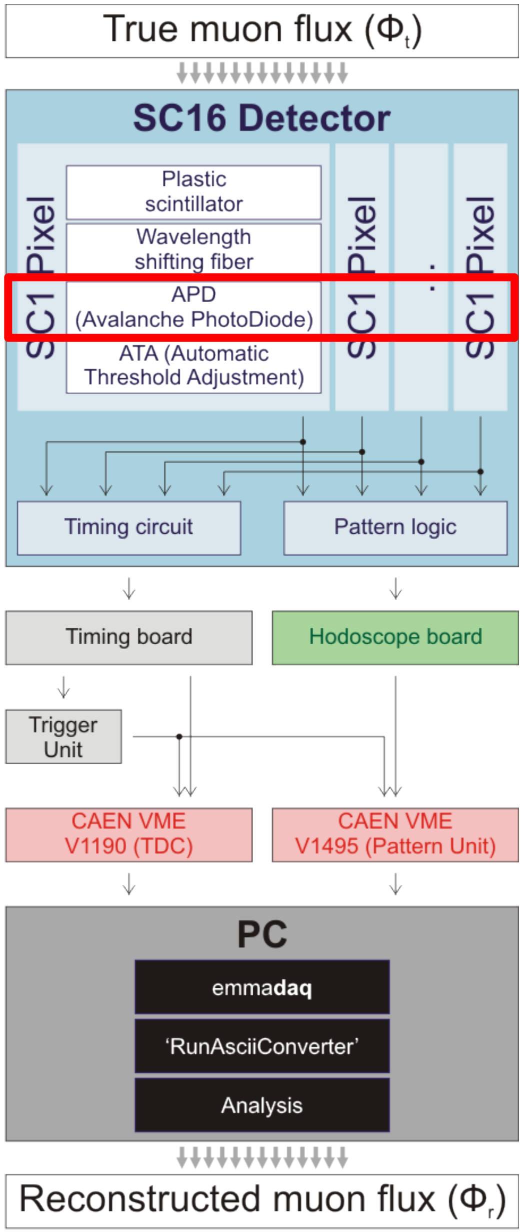
Because of big number of photons produced efficiency is still ~100% at this stage.





Side note:

Timing depends on the number of photons arriving to APD
→ **more** photons → **steeper** the front edge of the pulse
→ detection threshold reached **faster & with less fluctuations**



If discrimination threshold = 23 pe
→ Rate = 3.7 Hz

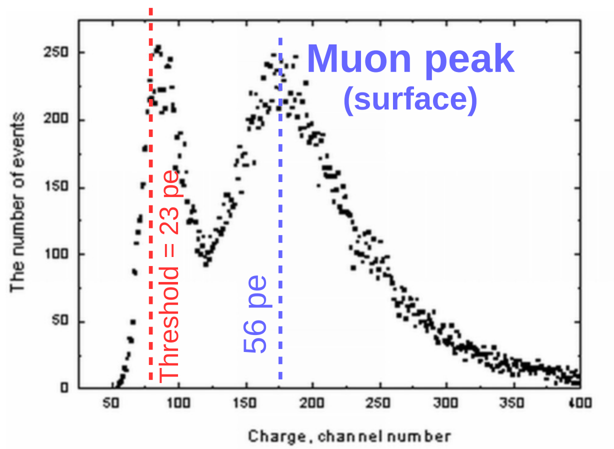


Figure 2. Charge spectrum of events detected with the scintillator counter in the surface laboratory.

If discrimination threshold = 23 pe
→ Rate = 1.26 Hz

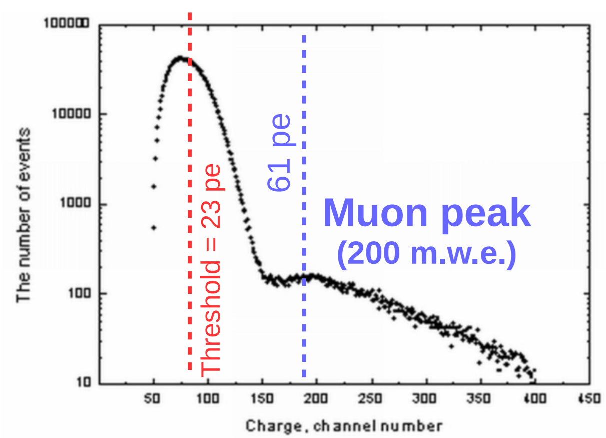


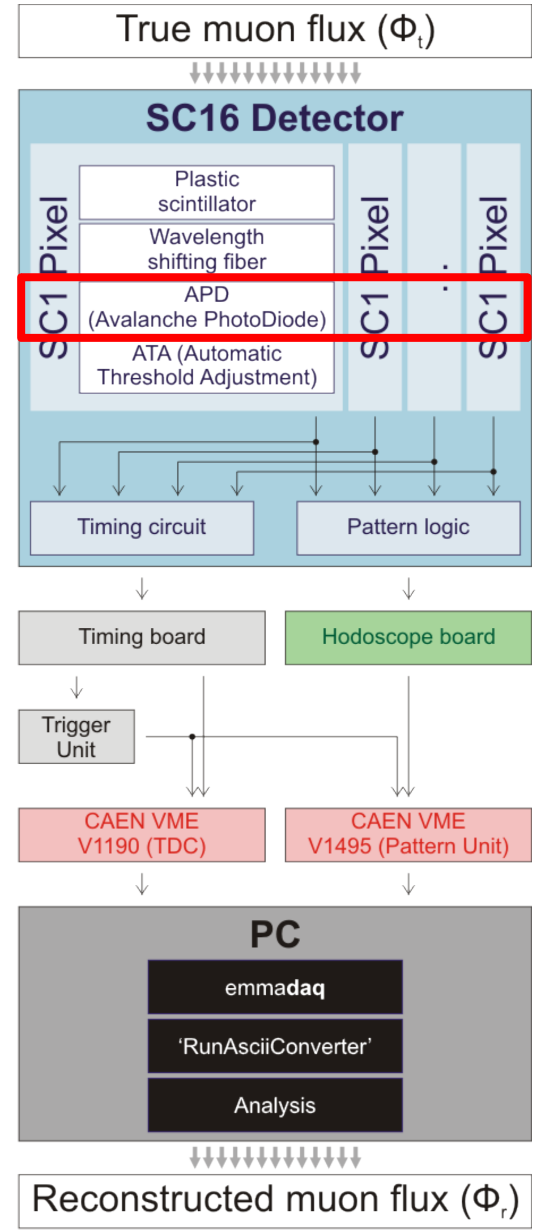
Figure 3. Charge spectrum of events detected with the scintillator counter at the underground laboratory at the depth of 200 m.w.e.

Avalanche Photodiode (2/2)

Side note:

Timing depends on the number of photons arriving to APD
→ **more** photons → **steeper** the front edge of the pulse
→ detection threshold reached **faster &** with **less fluctuations**

Because muon peak is **gaussian** – some **efficiency** is lost due to threshold setting → see next slide



If discrimination threshold = 23 pe
→ Rate = 3.7 Hz

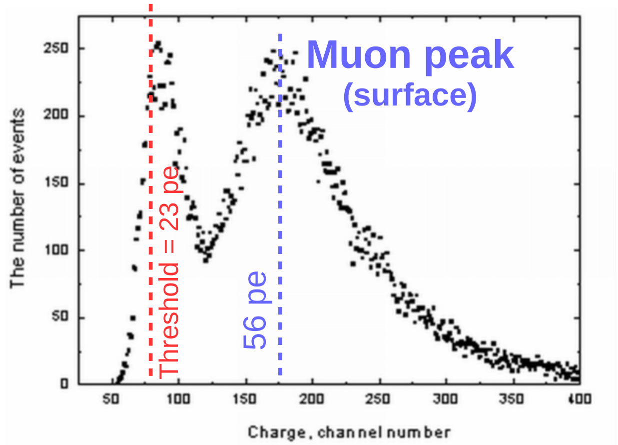


Figure 2. Charge spectrum of events detected with the scintillator counter in the surface laboratory.

If discrimination threshold = 23 pe
→ Rate = 1.26 Hz

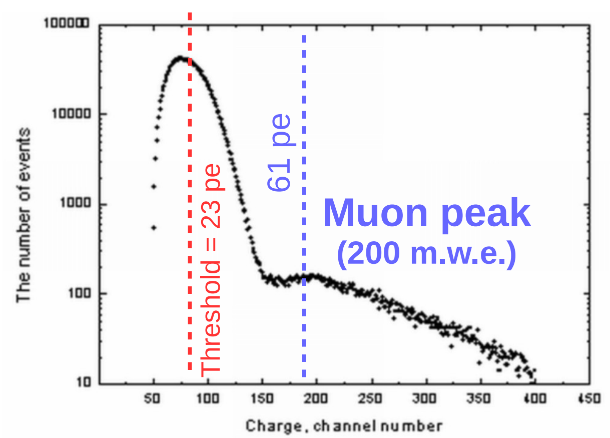
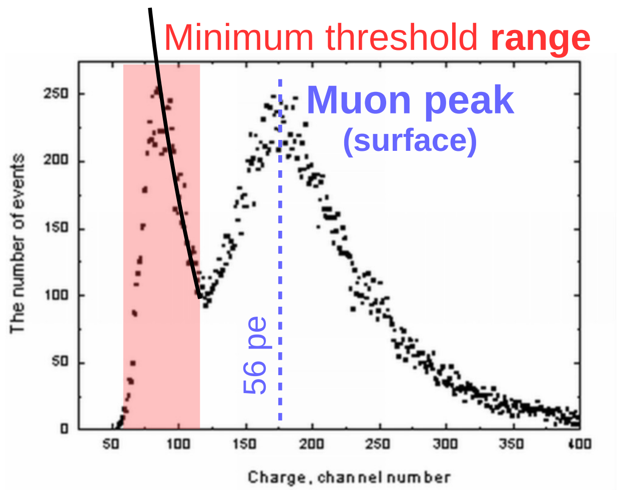


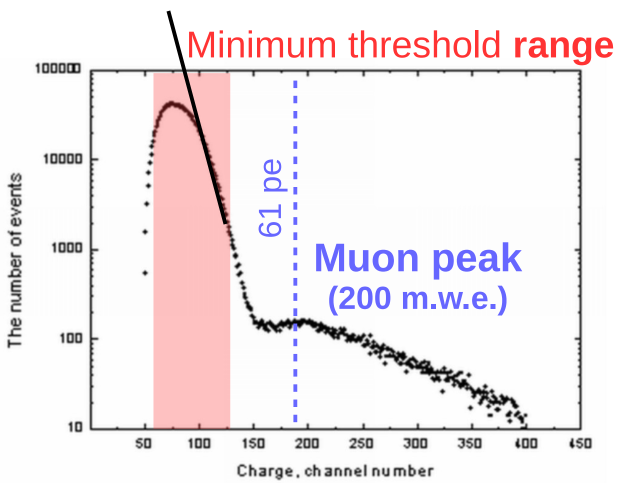
Figure 3. Charge spectrum of events detected with the scintillator counter at the underground laboratory at the depth of 200 m.w.e.

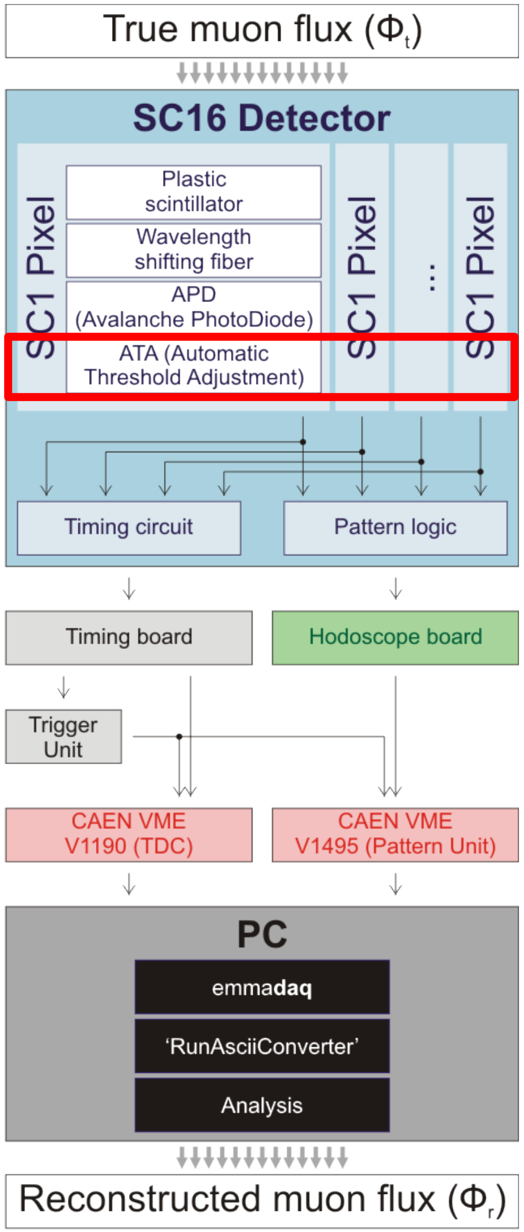
Automatic Threshold Adjustment (1/3)

→ **ATA** => Threshold voltage is adjusted so that counting rate is kept at ~5 Hz for each pixel independently

→ The **dynamic range** of adjustment is **limited** => there exists a **minimum threshold**

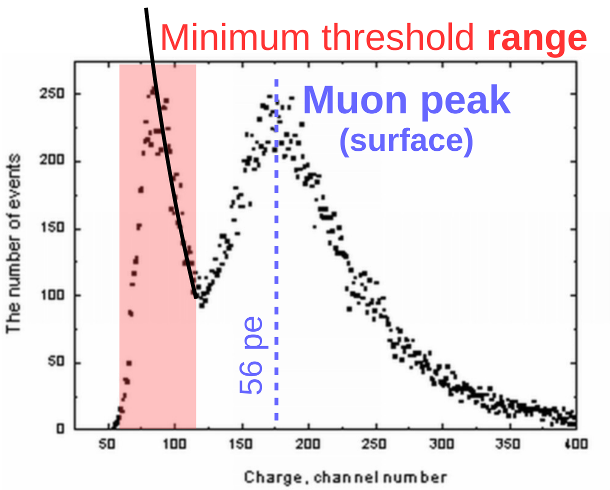


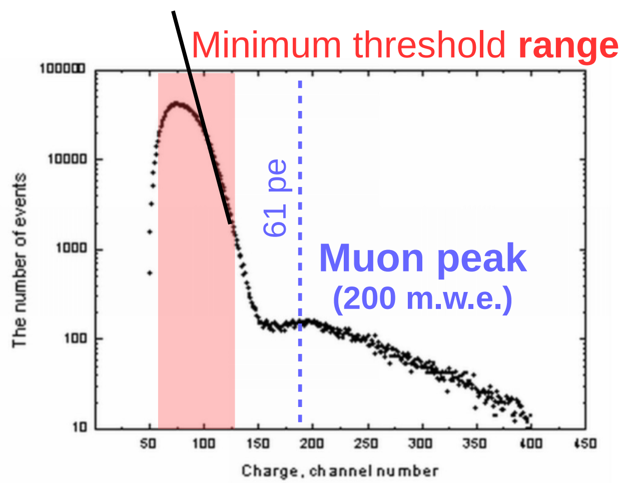


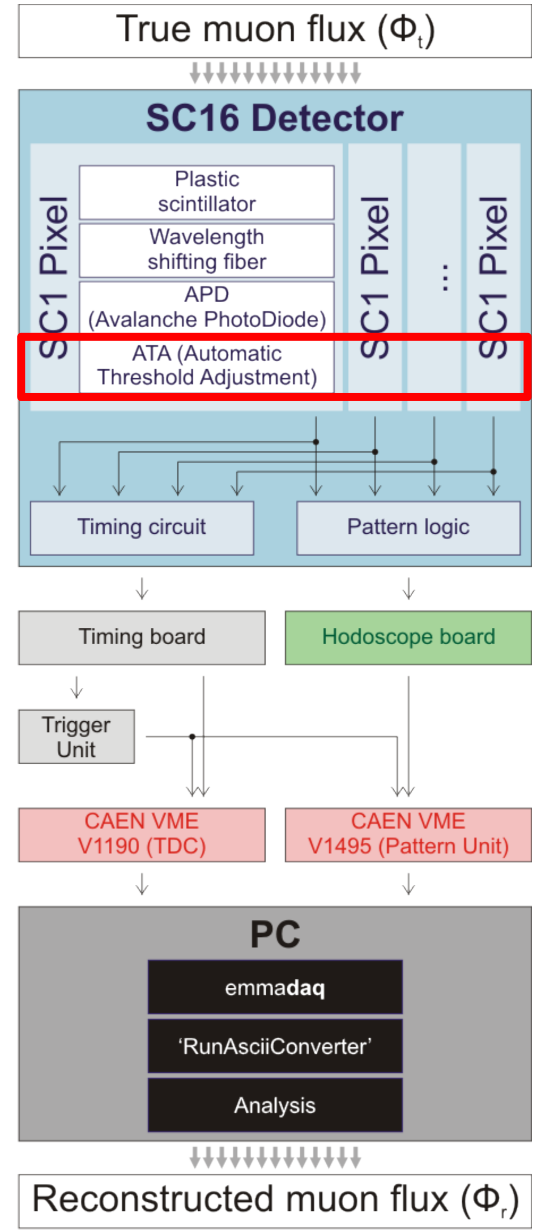


Automatic Threshold Adjustment (2/3)

- → **ATA** => Threshold voltage is adjusted so that counting rate is kept at ~5 Hz for each pixel independently
- → The **dynamic range** of adjustment is **limited** => there exists a **minimum threshold**
- → If the muon flux is low
  => little high-energy (>~2.5MeV) gamma background is present
  => the **minimum threshold** is reached
  => counting rate drops below 5 Hz







Automatic Threshold Adjustment (3/3)

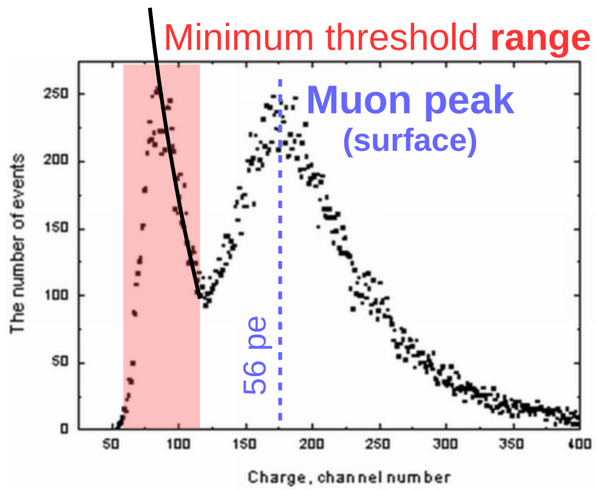
→ **ATA** => Threshold voltage is adjusted so that counting rate is kept at ~5 Hz for each pixel independently

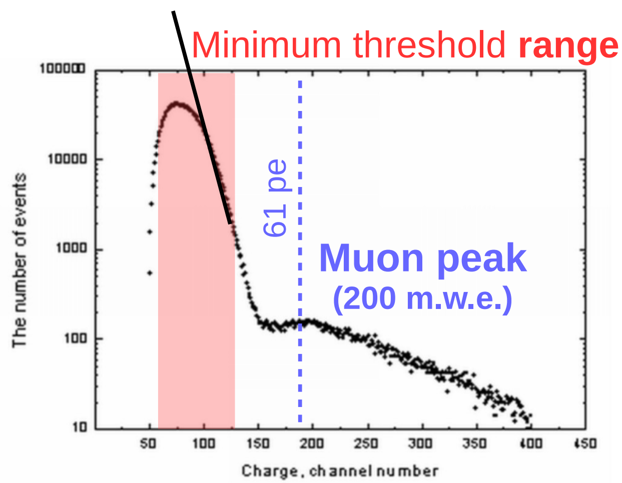
→ The **dynamic range** of adjustment is **limited**
=> there exists a **minimum threshold**

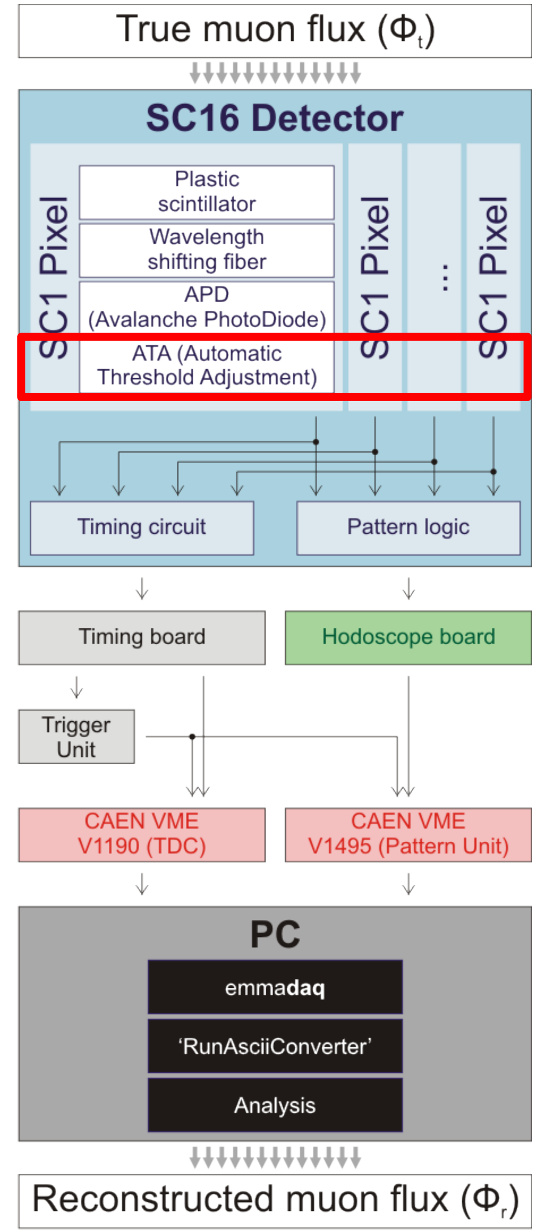
→ If the muon flux is low
=> little high-energy (>~2.5MeV) gamma background is present
=> the **minimum threshold** is reached
=> counting rate drops below 5 Hz

→ Each pixel is an individual entity, one slightly different form another
=> the minimum threshold can also vary slightly, causing
=> very **small differences in efficiencies** between different pixels*

* The **minimum threshold** is located on the far left side of the Gaussian tail of the muon spectrum (low deposited energy), so it is not a significant effect

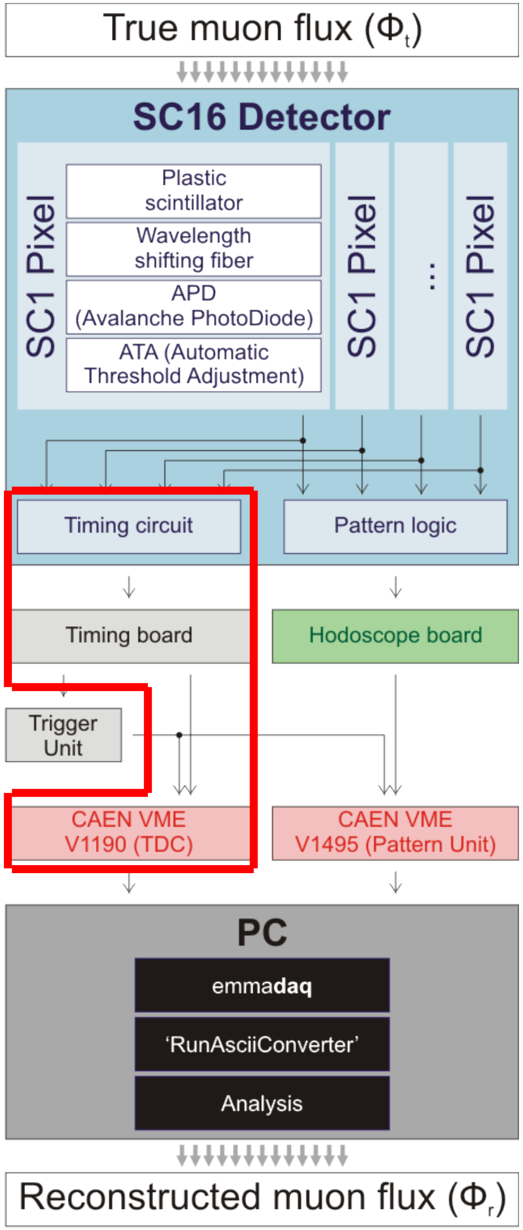






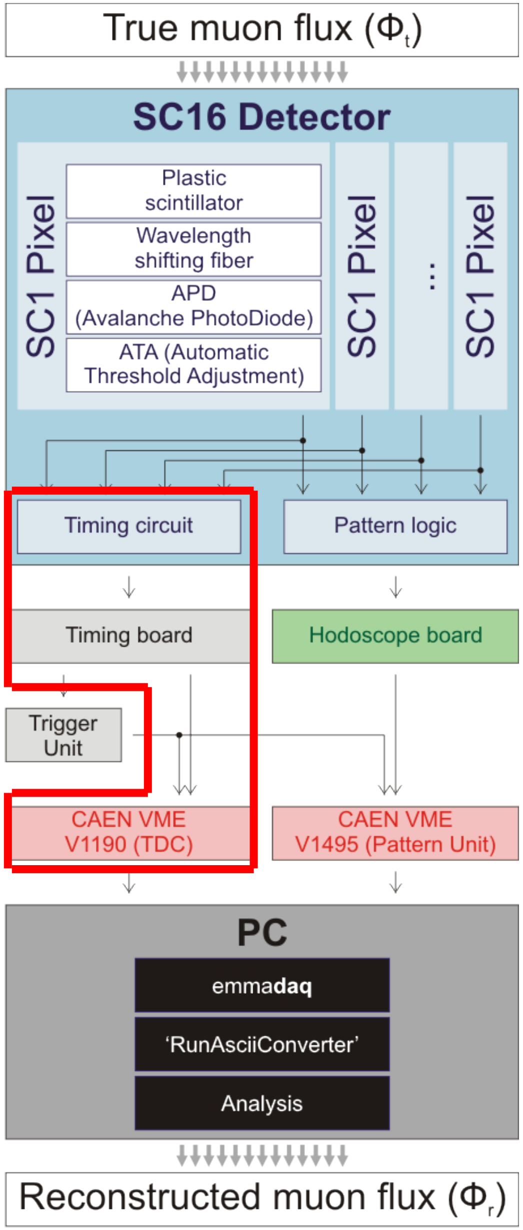
Time Chain (1/4)

→ If **more than one pixel** was hit in an SC16
=> only the time of the earliest one will be recorded and assigned to the whole SC16 detector
=> There is no way to recover the timing info from other hit pixels (apart from hardware constraint of 50 ns window in the HB → see slide 10)



- → If **more than one pixel** was hit in an SC16
  - => only the time of the earliest one will be recorded and assigned to the whole SC16 detector
  - => There is no way to recover the timing info from other hit pixels (apart from hardware constraint of 50 ns window in the HB → see slide 10)
- → The VME TDC is set to accept and record data from relatively wide time range:
  - => **window width = 2 μs**, offset = -2.8 μs)
    - ie. event acquisition time:
      - → starts 0.8 us before the trigger and
      - → ends 1.2 us after the trigger
  - => the trigger is generated **~400 ns** after muon has passed through the detector

TODO: Verify 400 ns



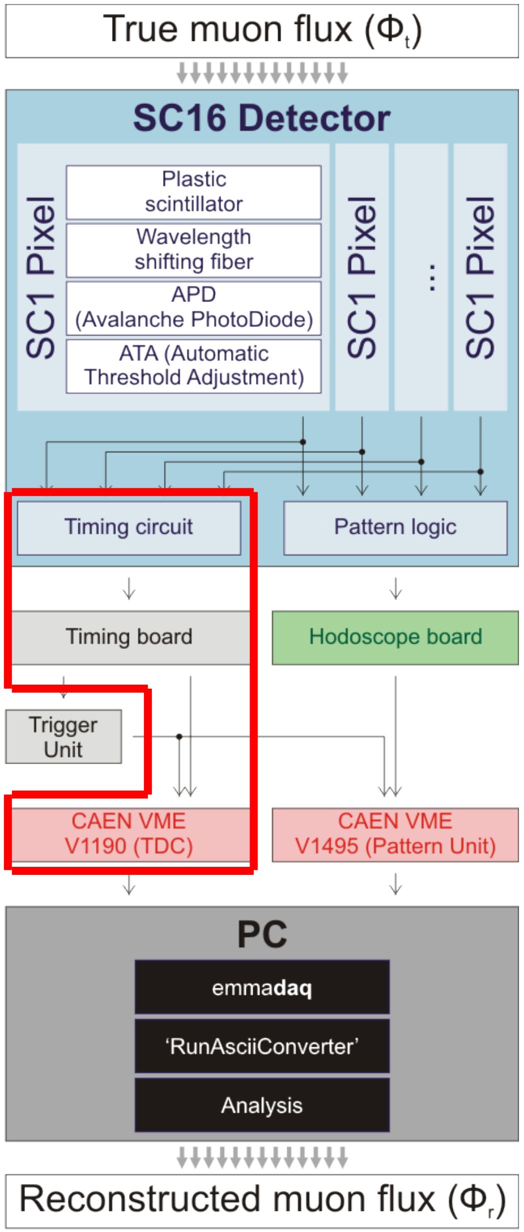
Time Chain (3/4)

→ If **more than one pixel** was hit in an SC16
  => only the time of the earliest one will be recorded and assigned to the whole SC16 detector
  => There is no way to recover the timing info from other hit pixels (apart from hardware constraint of 50 ns window in the HB → see slide 10)

→ The VME TDC is set to accept and record data from relatively wide time range:
  => **window width = 2 μs**, offset = -2.8 μs)
    ie. event acquisition time:
    → starts 0.8 us before the trigger and
    → ends 1.2 us after the trigger
  => the trigger is generated **~400 ns** after muon has passed through the detector

TODO: Verify 400 ns

→ **Stricter time cuts** should be applied in software
  => include into analysis only the time-correlated hits
    → without time calibration: +/- 11 ns* from the mean value for each event



* 11 ns can be justified based on timing studies (next slide)

Time Chain (4/4)

→ If **more than one pixel** was hit in an SC16
  => only the time of the earliest one will be recorded and assigned to the whole SC16 detector
  => There is no way to recover the timing info from other hit pixels (apart from hardware constraint of 50 ns window in the HB → see slide 10)

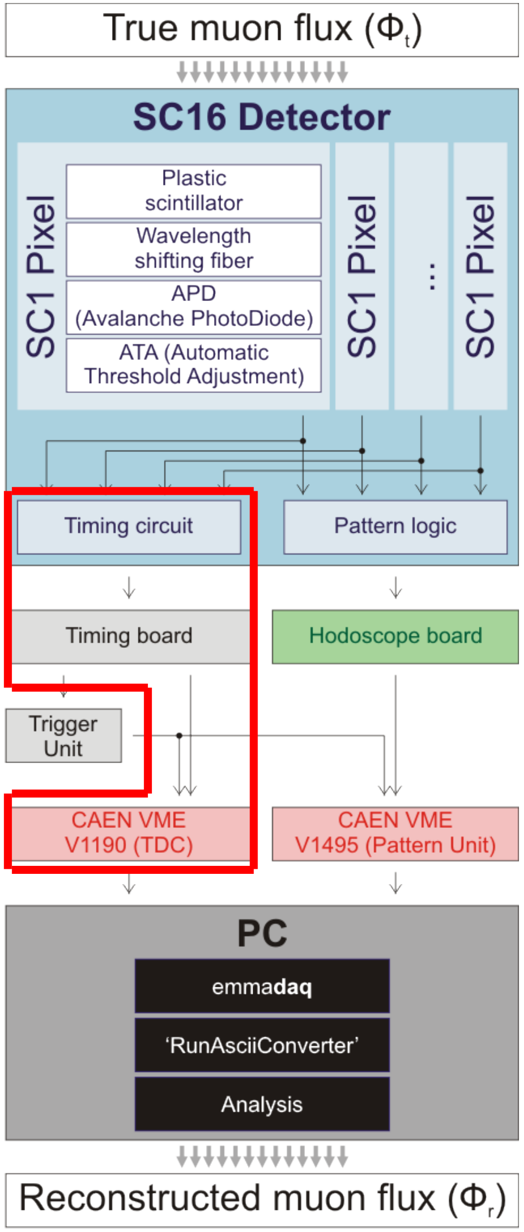
→ The VME TDC is set to accept and record data from relatively wide time range:
  => **window width = 2 μs**, offset = -2.8 μs)
    ie. event acquisition time:
      → starts 0.8 us before the trigger and
      → ends 1.2 us after the trigger
  => the trigger is generated **~400 ns** after muon has passed through the detector

TODO: Verify 400 ns

→ **Stricter time cuts** should be applied in software
  => include into analysis only the time-correlated hits
    → without time calibration: +/- 11 ns* from the mean value for each event

→ **No efficiency losses** on the hardware side

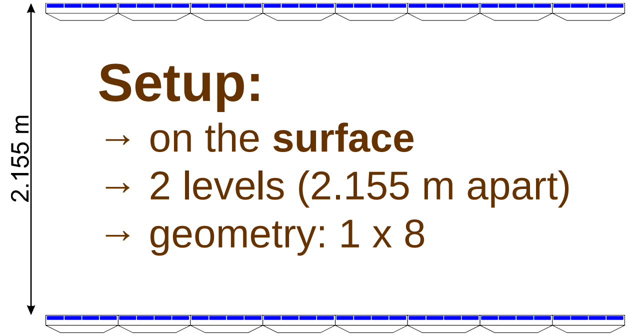
* 11 ns can be justified based on timing studies (next slide)



Extract from timing studies

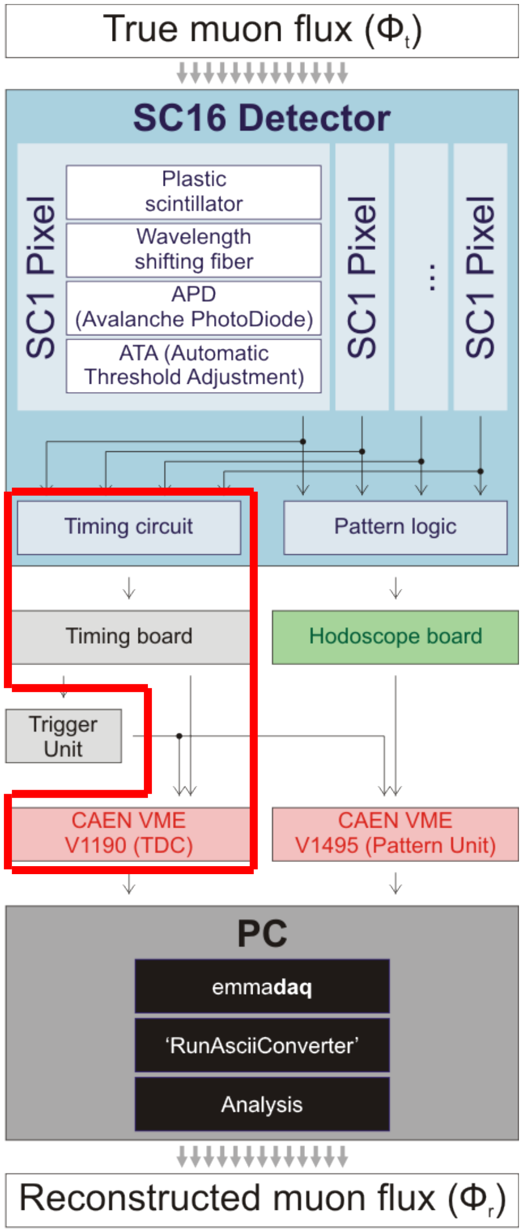
Conditions:

→ only **verticals** accepted
→ calculate the **time difference** between top and bottom pixel
=> 1 x 8 x 16 pixel pairs
=> 128 time distributions



Setup:

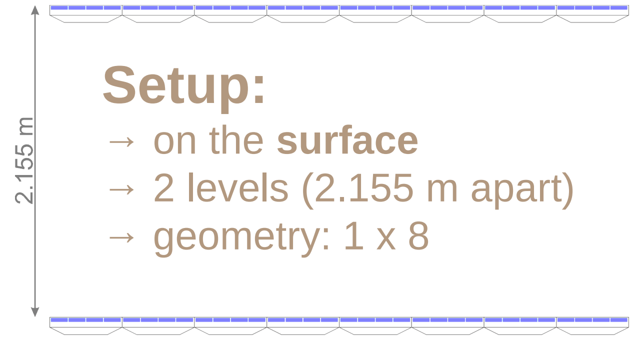
→ on the **surface**
→ 2 levels (2.155 m apart)
→ geometry: 1 x 8



Extract from timing studies

Conditions:

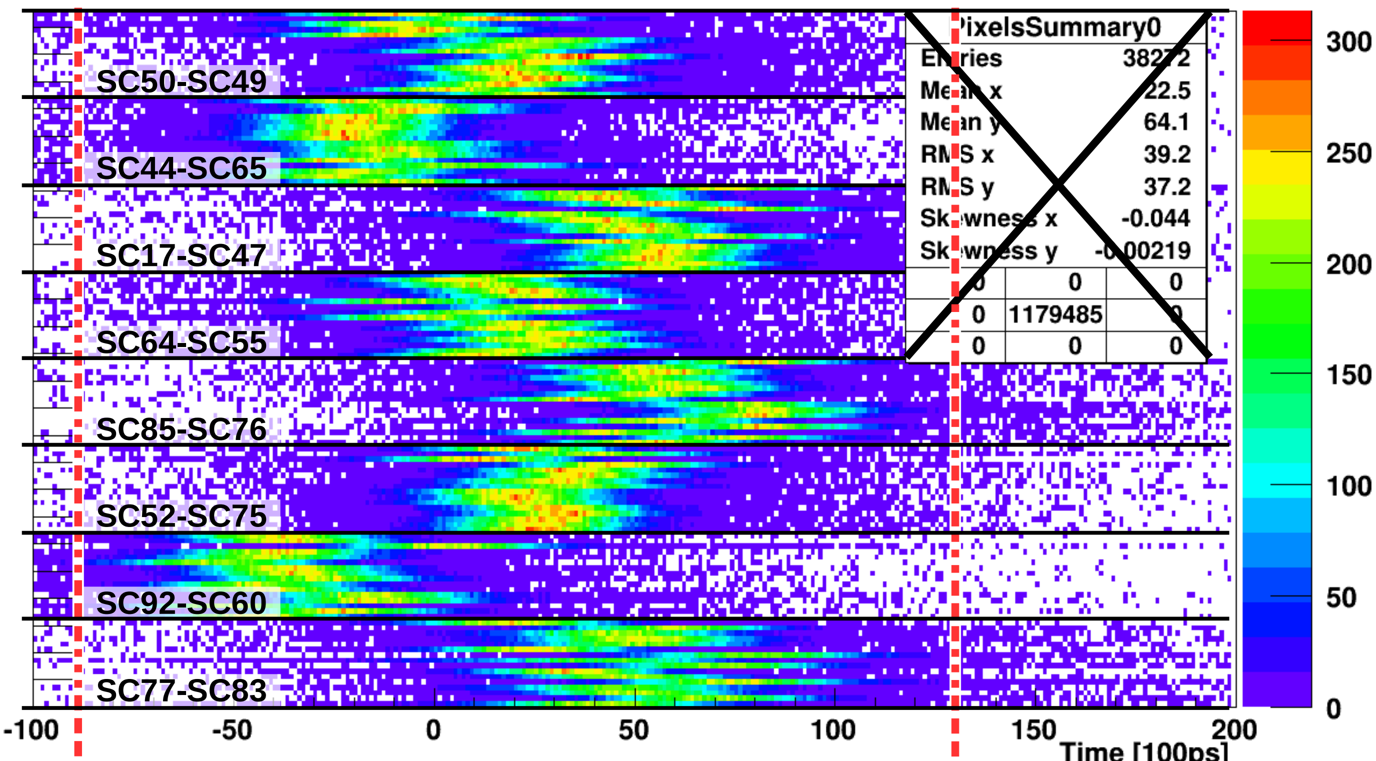
→ only **verticals** accepted
→ calculate the **time difference** between top and bottom pixel
=> 1 x 8 x 16 pixel pairs
=> 128 time distributions



Setup:

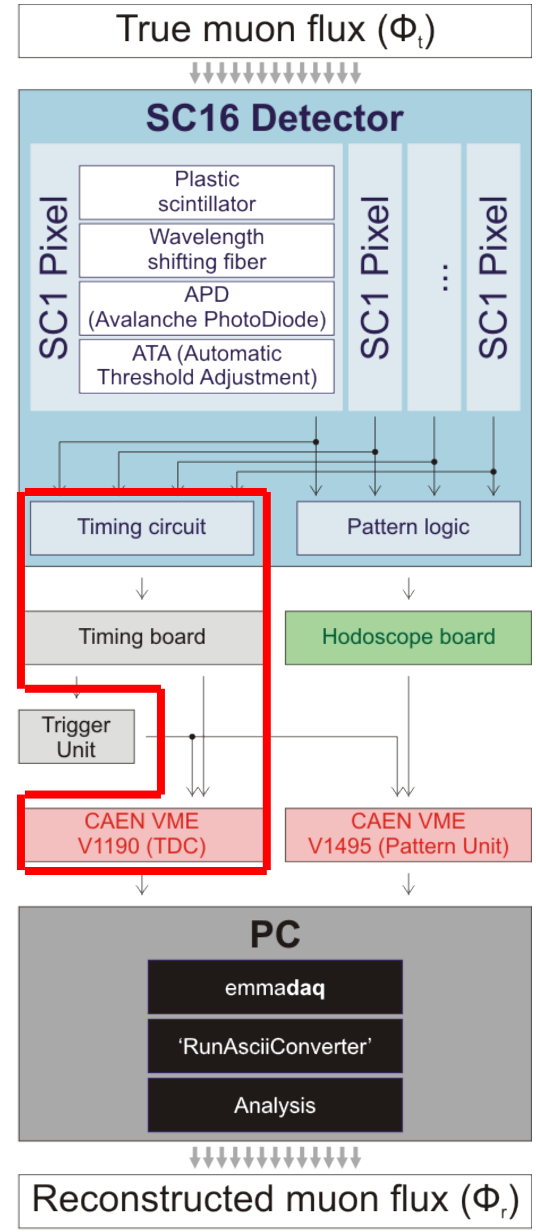
→ on the **surface**
→ 2 levels (2.155 m apart)
→ geometry: 1 x 8

← ΔT = 22 ns => **+/- 11 ns** →



T1 = -9 ns

T2 = 13 ns

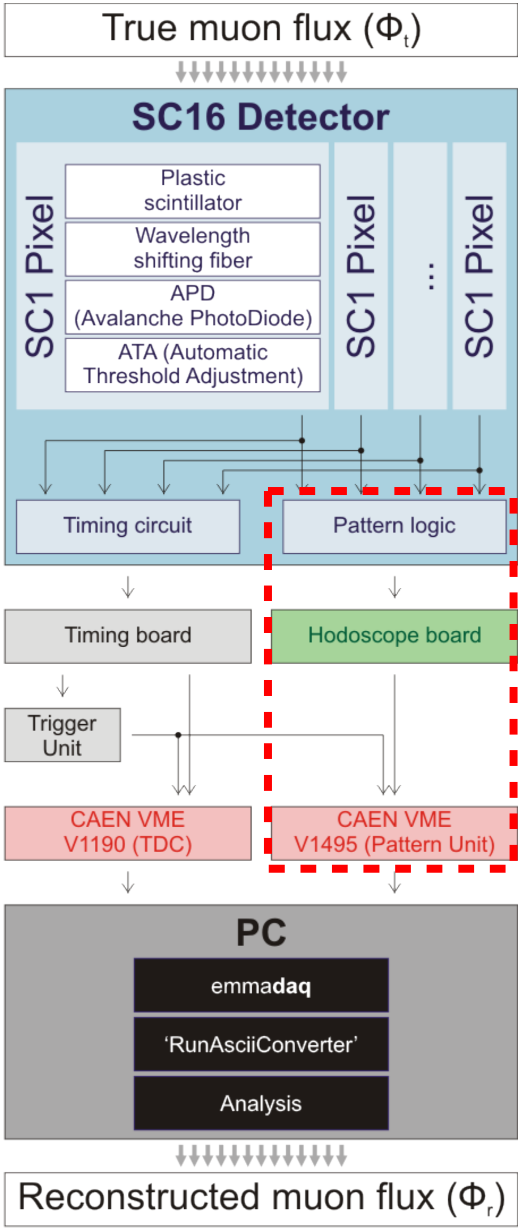


Covered signal paths:

→ Optical
→ Optical → electrical conversion (APD)
→ Automatic Threshold Adjustment (ATA)
→ Timing circuits

Upcoming:

→ Pattern pathway
→ Trigger logics
→ Software



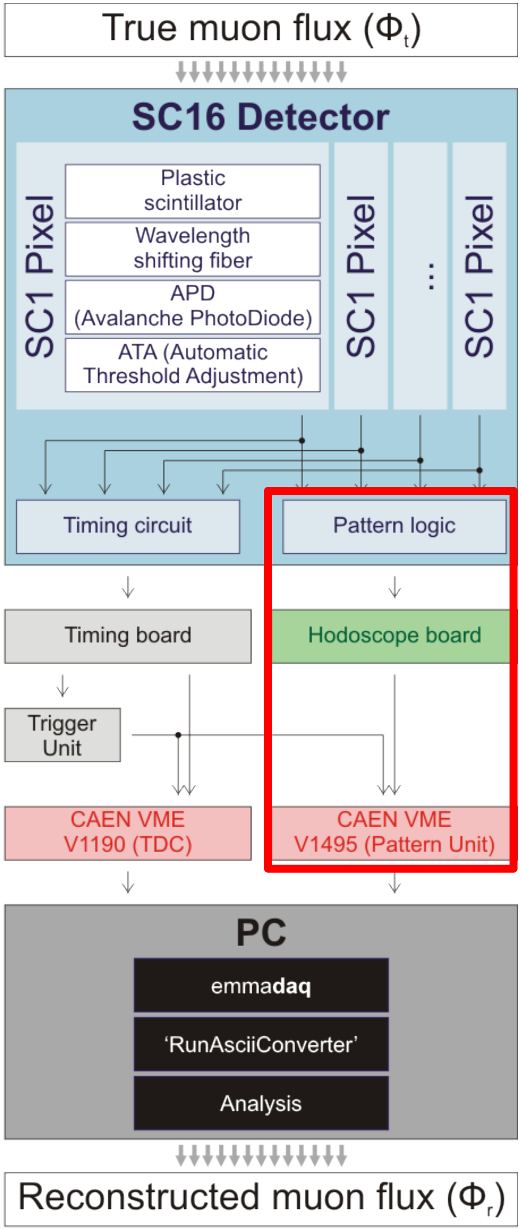
Pattern Chain (1/7)

Sketch of operation:

→ SC16's **Timing circuit** sends info about time of a hit to TB=>TDC

→ Within the same event the **Pattern circuit** of the same SC16 **should** send a corresponding pattern info to HB => Pattern Unit

→ **Sometimes pattern info is missing. Why?**



Sketch of operation:

→ SC16's **Timing circuit** sends info about time of a hit to TB=>TDC

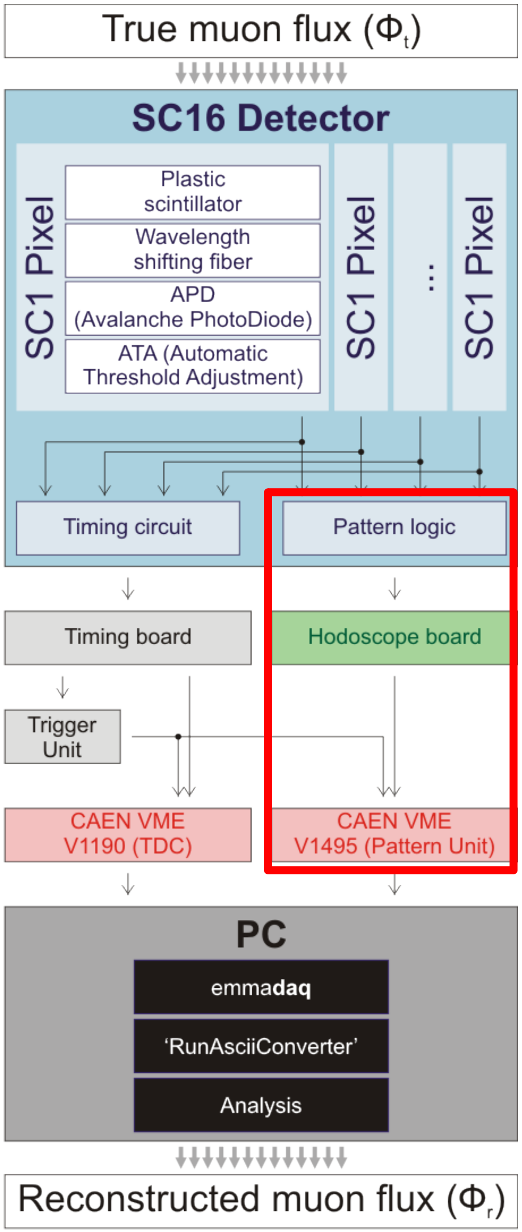
→ Within the same event the **Pattern circuit** of the same SC16 **should** send a corresponding pattern info to HB => Pattern Unit

→ **Sometimes pattern info is missing. Why?**

Partial explanation:

→ **Hodoscope Board** has an event buffer 50 ns long.
=> If two hits are separated by **more than 50 ns** then
=> Only the last one will be recorded

→ It is possible to loose pattern data from a valid muon event if:
=> the trigger arrives **too late** and data is not read out before
=> the next 'local event' (gamma background, muon, noise
no need for a trigger!), which follows real data at a very
specific and relatively narrow **time window** (width: ~200 ns)
=> Probability estimation:
→ 352 pixels · 200 ns · 5 Hz = 3.5e-4 « 1%
=> Very unlikely (thanks to ATA) => **not the answer**



Sketch of operation:

→ SC16's **Timing circuit** sends info about time of a hit to TB=>TDC

→ Within the same event the **Pattern circuit** of the same SC16 **should** send a corresponding pattern info to HB => Pattern Unit

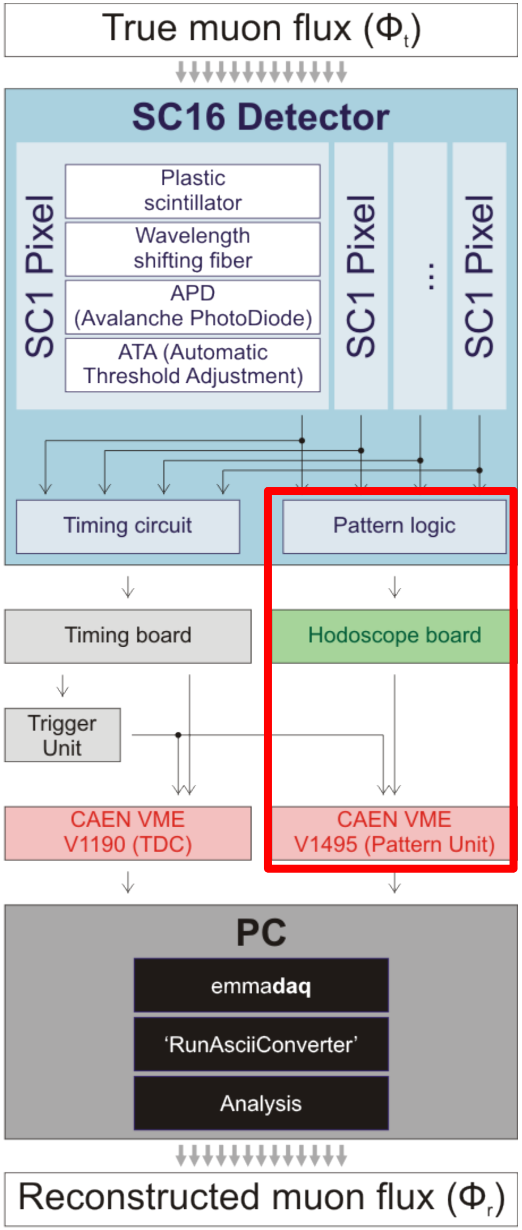
→ **Sometimes pattern info is missing. Why?**

Partial explanation:

→ **Hodoscope Board** has an event buffer 50 ns long.
=> If two hits are separated by **more than 50 ns** then
=> Only the last one will be recorded

→ It is possible to loose pattern data from a valid muon event if:
=> the trigger arrives **too late** and data is not read out before
=> the next 'local event' (gamma background, muon, noise no need for a trigger!), which follows real data at a very specific and relatively narrow **time window** (width: ~200 ns)
=> Probability estimation:
→ 352 pixels · 200 ns · 5 Hz = 3.5e-4 « 1%
=> Very unlikely (thanks to ATA) => **not the answer**

→ This probability **should be checked** from the collected data
=> Apply a time cut of 22 / 6 ns (non-calibrated / calibrated data)
=> Check in how many events pattern data is missing if time info is present for a given SC16
=> Compare with scenario without the time cut



Pattern Chain (4/7)

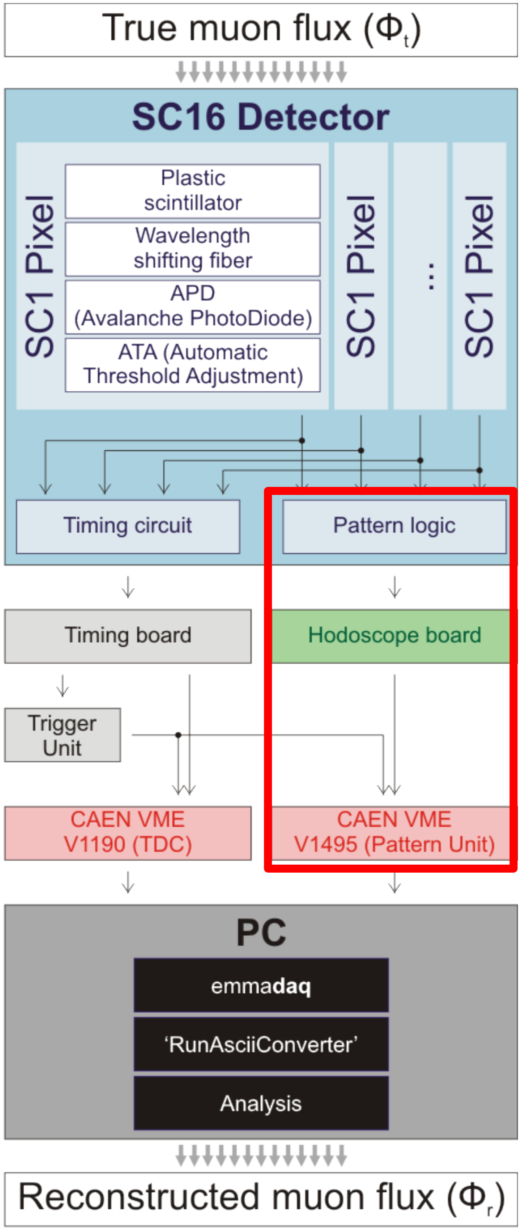
Experimentally up to 60% losses (in worst SC16s) are observed, depending on:

→ Total number of SC16 connected to the system
=> **More SC16s => more losses**

→ Trigger rate
=> **Lower rate => more losses**

→ Location of an SC16 within setup
=> **Remote location => more losses**
=> Remote = away from the center
=> Lower probability to be hit by a triggered event

→ Participation of an SC16 in trigger generation
=> **Non-triggering SC16 => more losses**



Pattern Chain (5/7)

Experimentally up to 60% losses (in worst SC16s) are observed, depending on:

→ Total number of SC16 connected to the system
=> **More SC16s => more losses**

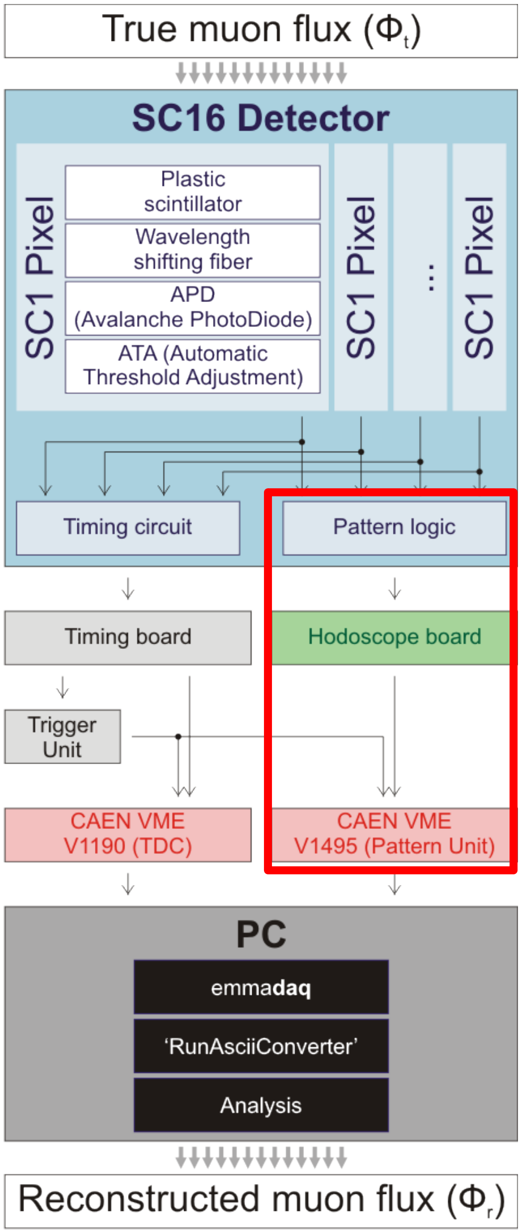
→ Trigger rate
=> **Lower rate => more losses**

→ Location of an SC16 within setup
=> **Remote location => more losses**
=> Remote = away from the center
=> Lower probability to be hit by a triggered event

→ Participation of an SC16 in trigger generation
=> **Non-triggering SC16 => more losses**

Are all of these really losses?

=> There is a small **known component**:
A number of events (~15) at the end of every data file misses pattern info:
→ It is caused by a **known bug** of Pattern Unit firmware
→ It only occurs when retrieving a non-full data buffer (end-of-file)
→ The acquisition time should be reduced by **~15s** for every file
→ The exact effective acquisition time can be checked for each file

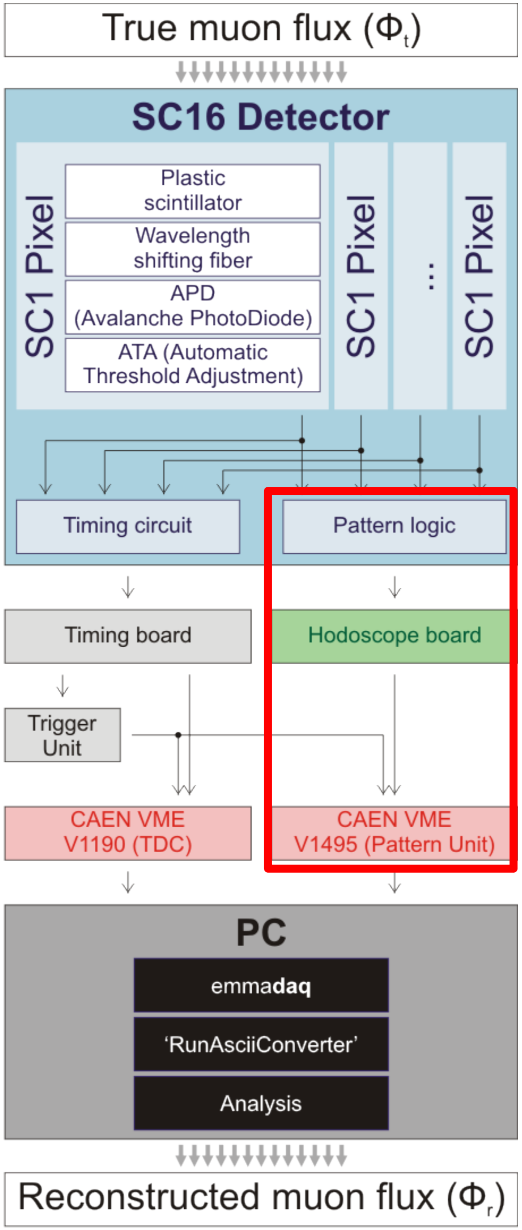


Pattern Chain (6/7)

Note:

→ What Alberto used to call **'efficiency'** is actually the ratio between the number of events, in which:
=> the time information and pattern information of a particular SC16 was present and
=> only the time information for the same SC16 was present

→ It is **not** related to the **pixel efficiency** to detect a muon



Pattern Chain (7/7)

Note:

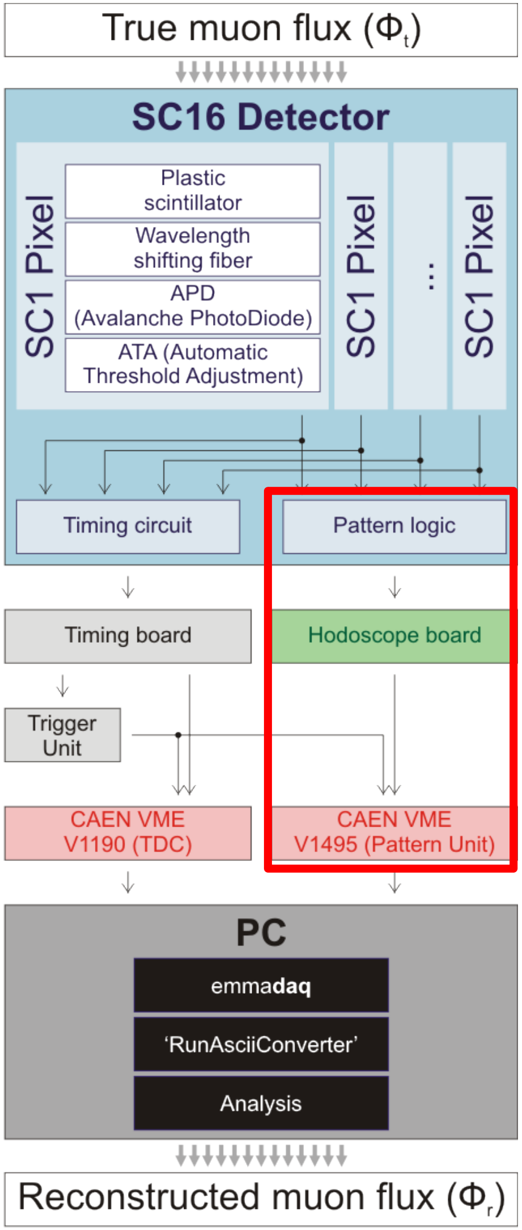
→ What Alberto used to call **'efficiency'** is actually the ratio between the number of events, in which:
=> the time information and pattern information of a particular SC16 was present and
=> only the time information for the same SC16 was present

→ It is **not** related to the **pixel efficiency** to detect a muon

These times should be verified = measured

Pattern data transfer and timing

→ Relaxation time required for APD: 700 ns
→ Serializing (SC): 750 ns (15 x 50 ns)
→ Cable length (15 / 30 m): 75 / 150 ns
→ Deserializing (HB): 460 / 750 ns (clk: 35 / 20 MHz)
=> **Total maximum delay: 1650 ns**
=> **HB cannot accept triggers earlier!**

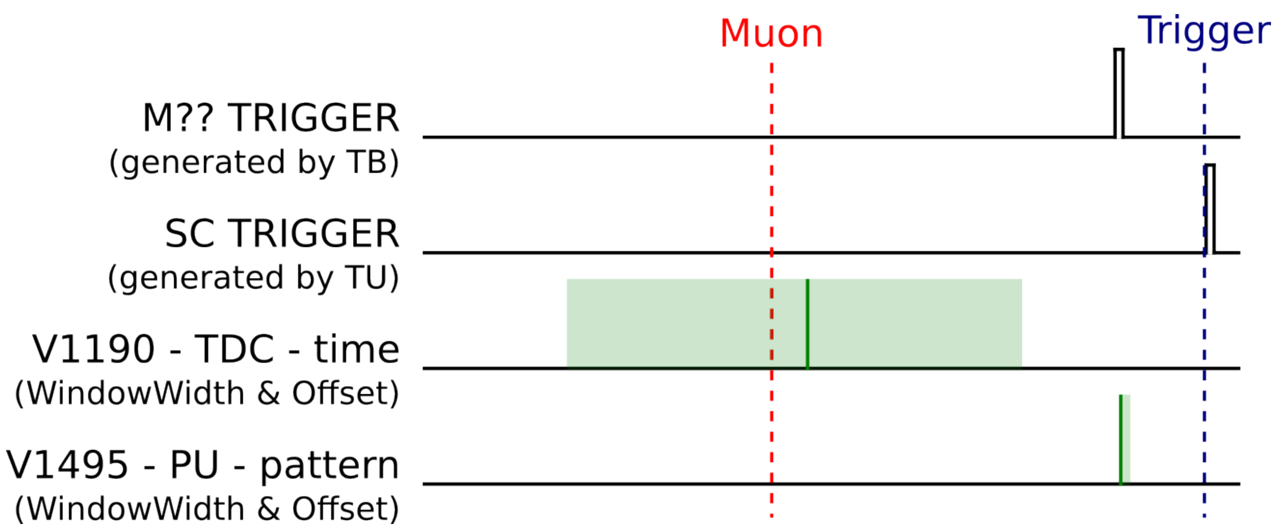


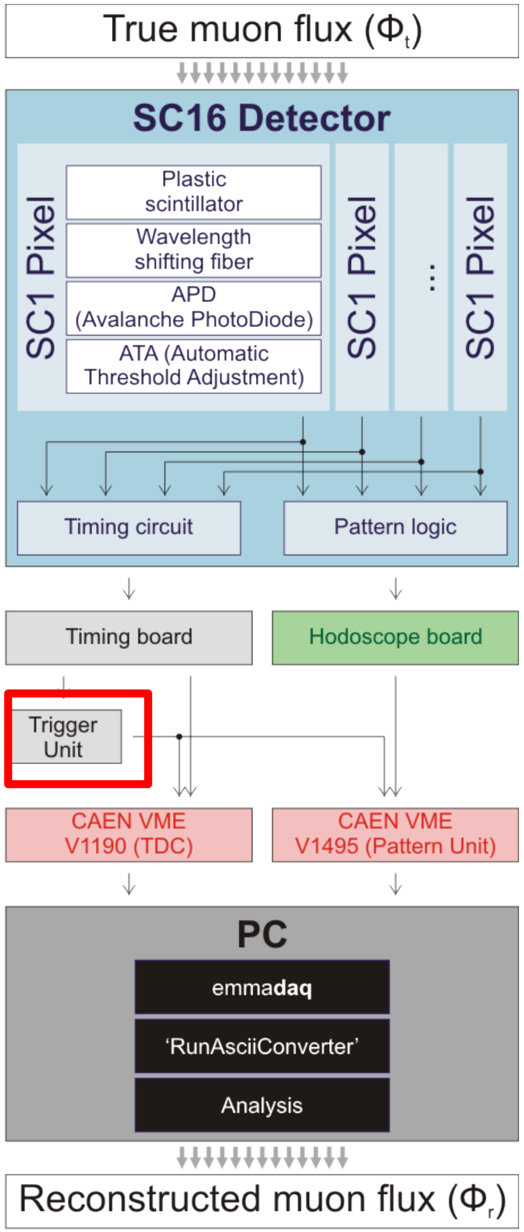
Trg <= OrTop **AND** OrBottom

→ Only **TB signals** are used for trigger generation

→ All VME modules require (identical) trigger

=> Trigger (event) numbers are the only way to **synchronize** data between several VME modules





Trigger (2/3)

Trg <= OrTop **AND** OrBottom

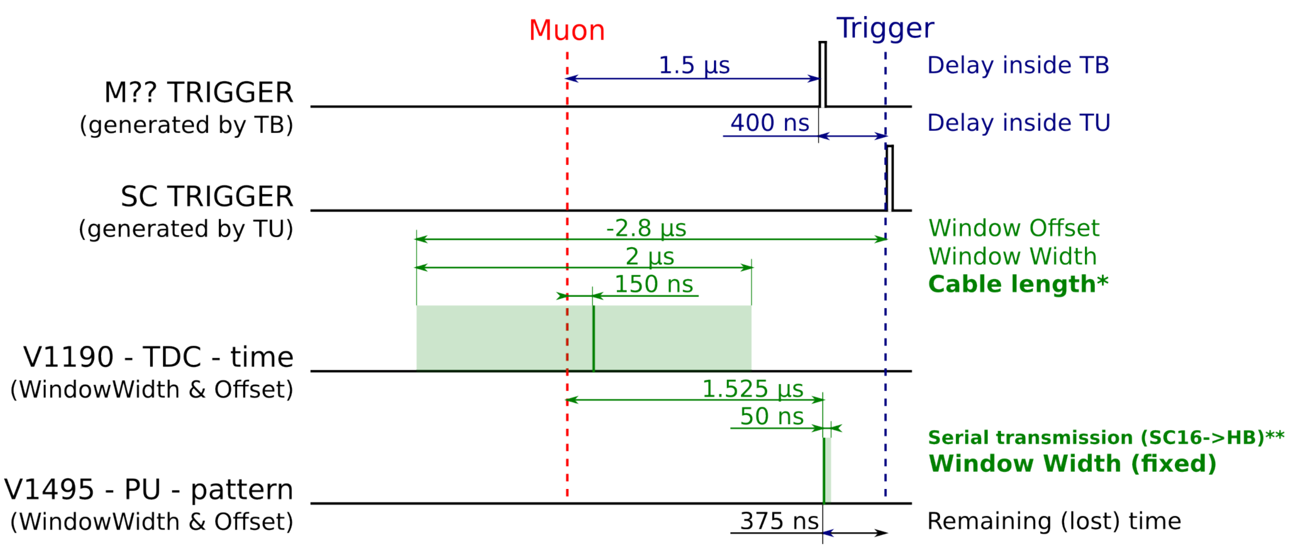
→ Only **TB signals** are used for trigger generation

→ All VME modules require (identical) trigger
=> Trigger (event) numbers are the only way to **synchronize** data between several VME modules

To accommodate HB's time requirement for trigger

→ TB's outputs are **delayed** by ~1.5 μs

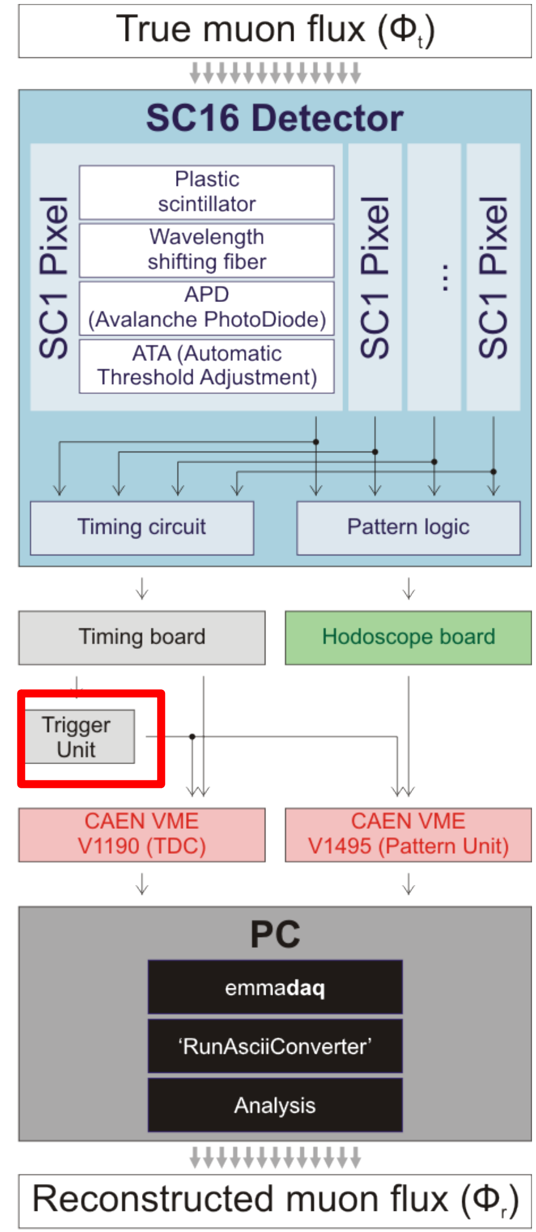
→ Internal **delay** of Trigger Unit is additional 400 ns



*Internal delay of TB is not included

**APD relaxation time (700) + serializing (15*50) + cable length (75) = 1525 ns

All times with respect to muon time do not take into account any delays inside SC16



Trigger Unit features **dead time** generator

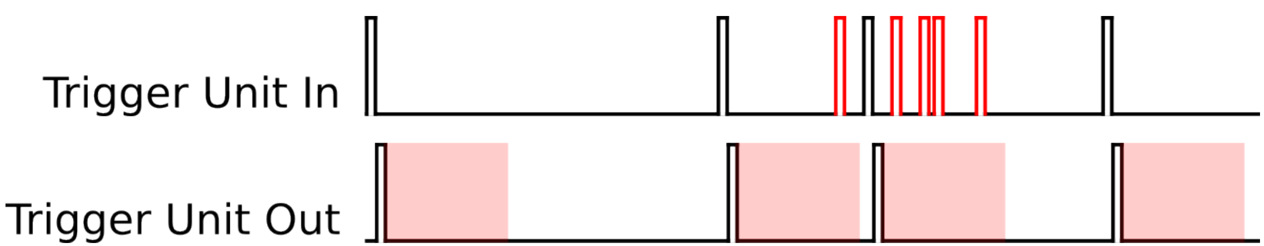
→ **Dead time** = no following trigger will be generated after the first trigger for a given time (50 μs → it can be checked from data)

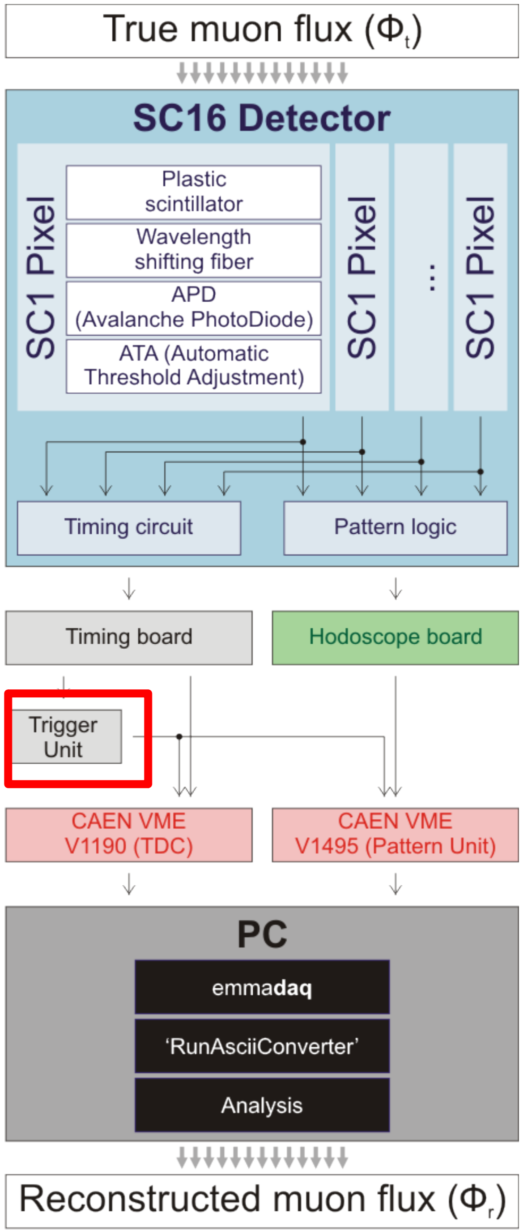
→ Different parts of the MM => different delays and acquisition times

→ **Dead time** prevents problems concerning forming of the event structure inside Memory buffers of the VME modules:

=> **Misalignment** of event numbers between different VME modules

=> A faster module (with shorter inherent busy time) may register 2 events, while the slower one is still transferring the data from the first event (and ignores the trigger)





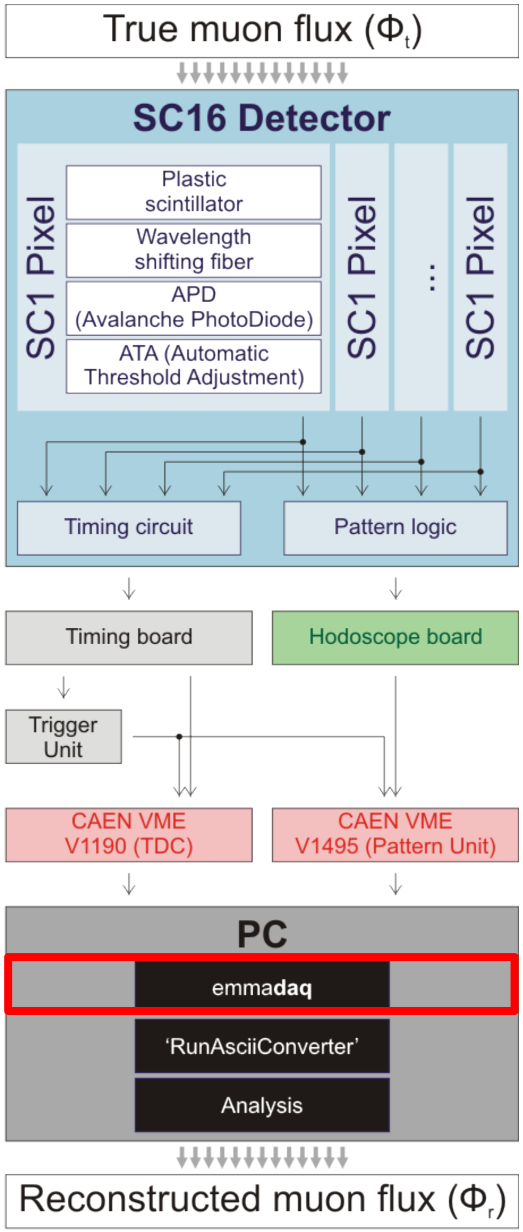
emmadaq

→ Communicates with VME modules via:

=> CAENVmeLib

=> CAEN drivers of A2818 (PCI optical link)

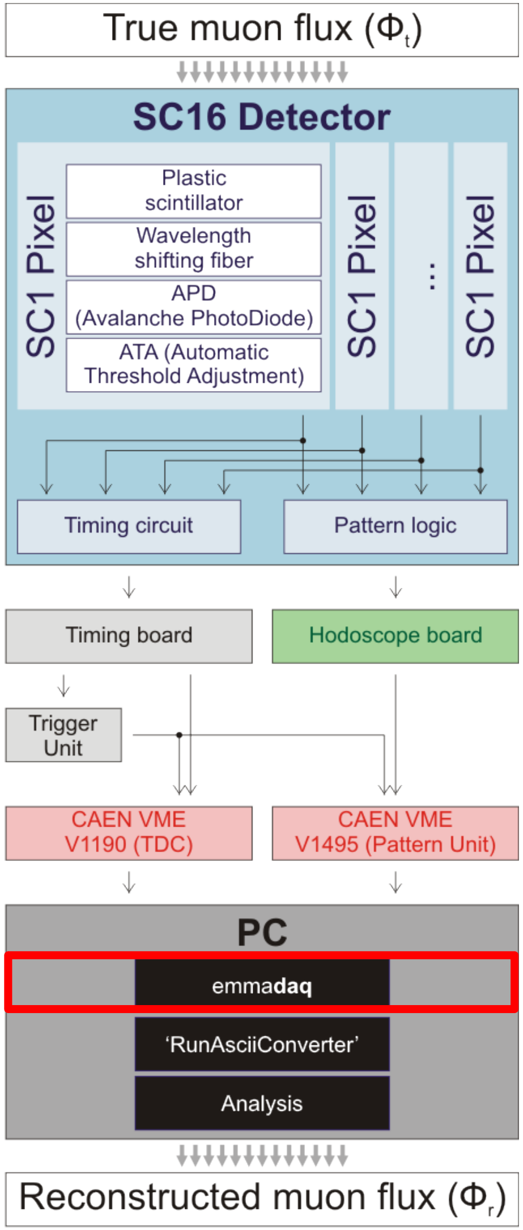
=> V2718 (VME controller)



emmadaq

→ Communicates with VME modules via:
=> CAENVmeLib
=> CAEN drivers of A2818 (PCI optical link)
=> V2718 (VME controller)

→ VME modules:
=> V1190 → **TDC** (Time-to-Digital Converter)
=> V1495 → **Pattern Unit** (with programmable FPGA)
=> V830 → **Scaler**

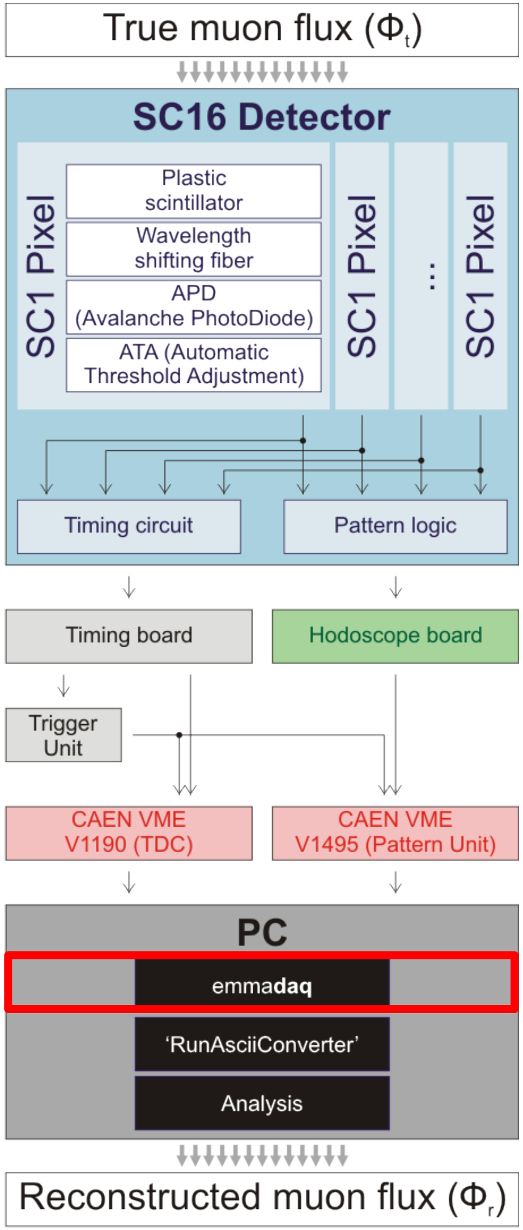


emmadaq

→ Communicates with VME modules via:
- => CAENVmeLib
- => CAEN drivers of A2818 (PCI optical link)
- => V2718 (VME controller)

→ VME modules:
- => V1190 → **TDC** (Time-to-Digital Converter)
- => V1495 → **Pattern Unit** (with programmable FPGA)
- => V830 → **Scaler**

→ Functionality:
- => Configuration of modules (read .conf files)
- => Online control (IRQ handling)
- => Download data from modules
- => Preprocess data
  - => Rearrange data bits inside every word
  - => Relevant **data** is **not modified** otherwise
- => Save to .emma binary file
- => Control reset and reconfiguration of modules every hour, save data in **separate 1-hour files**



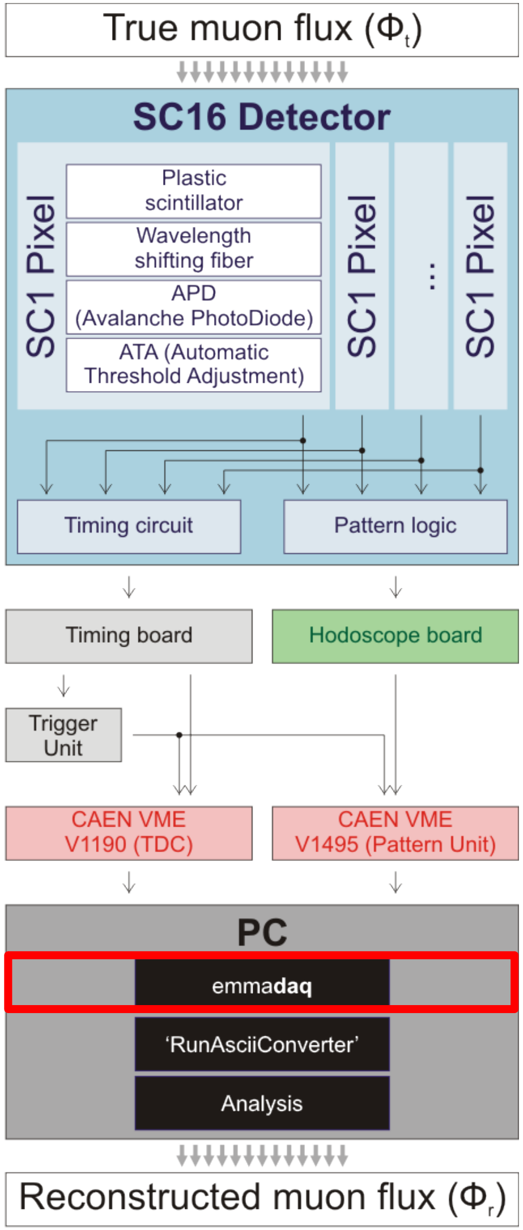
emmadaq

→ Communicates with VME modules via:
  => CAENVmeLib
  => CAEN drivers of A2818 (PCI optical link)
  => V2718 (VME controller)

→ VME modules:
  => V1190 → **TDC** (Time-to-Digital Converter)
  => V1495 → **Pattern Unit** (with programmable FPGA)
  => V830 → **Scaler**

→ Functionality:
  => Configuration of modules (read .conf files)
  => Online control (IRQ handling)
  => Download data from modules
  => Preprocess data
    => Rearrange data bits inside every word
    => Relevant **data** is **not modified** otherwise
  => Save to .emma binary file
  => Control reset and reconfiguration of modules every hour, save data in **separate 1-hour files**

→ **Raw data** is saved into binary files:
  => **no checks of data consistency** of the buffers sent via VME interface



RunAsciiConverter (emmareader)

→ Functionality

=> **Interprets raw data** stored in a binary file

→ **Splits** data into data chunks associated with modules

→ **Decodes** event and channel structure

→ **Detects data consistency errors**

=> Overflows of counters → **fixes them**

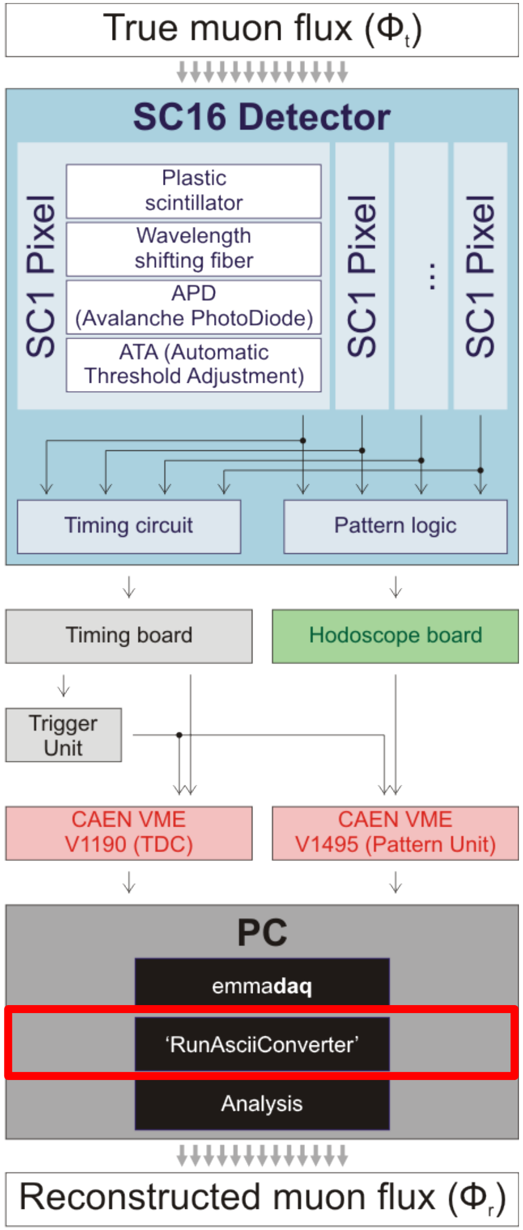
=> **Event structure corruption** → **marks file as bad**

→ Compares the total number of collected events with the last event number

→ Compares last event number between modules

→ Checks if event number counter starts from 0

→ Checks if every next event number is larger by 1 than the previous event number



RunAsciiConverter (emmareader)

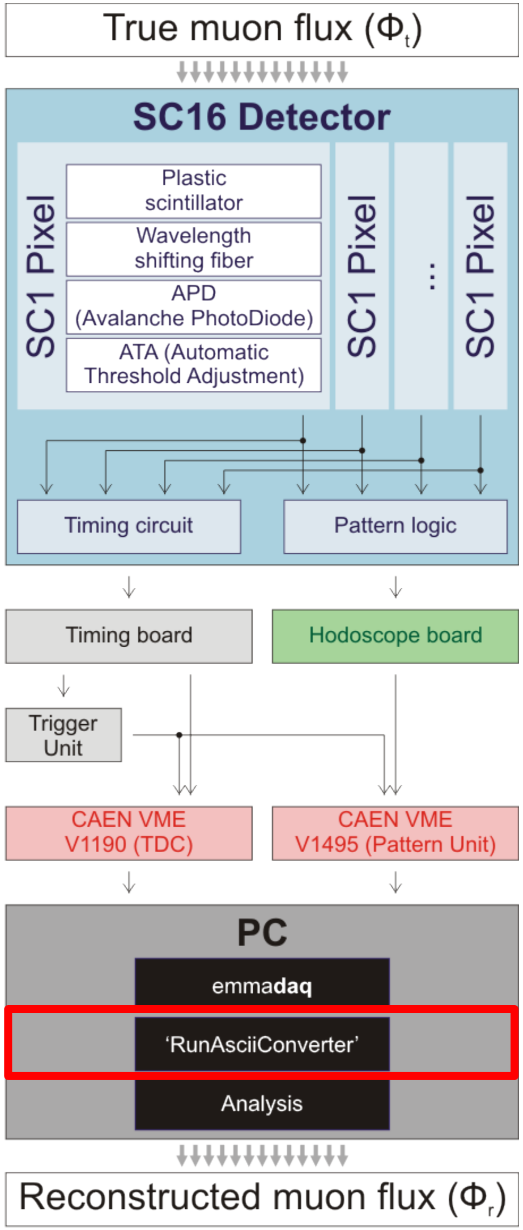
→ Functionality

=> **Interprets raw data** stored in a binary file

- → **Splits** data into data chunks associated with modules
- → **Decodes** event and channel structure
- → **Detects data consistency errors**
  - => Overflows of counters → **fixes them**
  - => **Event structure corruption** → **marks file as bad**
    - → Compares the total number of collected events with the last event number
    - → Compares last event number between modules
    - → Checks if event number counter starts from 0
    - → Checks if every next event number is larger by 1 than the previous event number

=> Transforms interpreted raw data into **detector-based** information

- → Reads map files
- → Transforms VME module and channel data into detector, pixel and data type (time or pattern) info
- → **No data checks** at this point (can be activated if needed)



RunAsciiConverter (emmareader)

→ Functionality

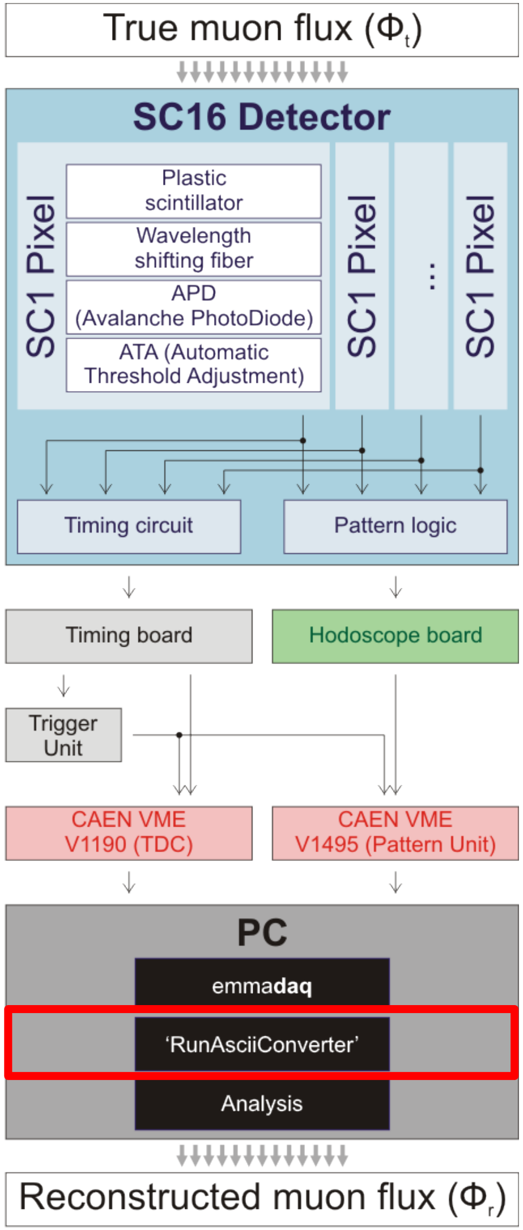
=> **Interprets raw data** stored in a binary file

- → **Splits** data into data chunks associated with modules
- → **Decodes** event and channel structure
- → **Detects data consistency errors**
  - => Overflows of counters → **fixes them**
  - => **Event structure corruption** → **marks file as bad**
    - → Compares the total number of collected events with the last event number
    - → Compares last event number between modules
    - → Checks if event number counter starts from 0
    - → Checks if every next event number is larger by 1 than the previous event number

=> Transforms interpreted raw data into **detector-based** information

- → Reads map files
- → Transforms VME module and channel data into detector, pixel and data type (time or pattern) info
- → **No data checks** at this point (can be activated if needed)

=> Saves the reconstructed data into ASCII file



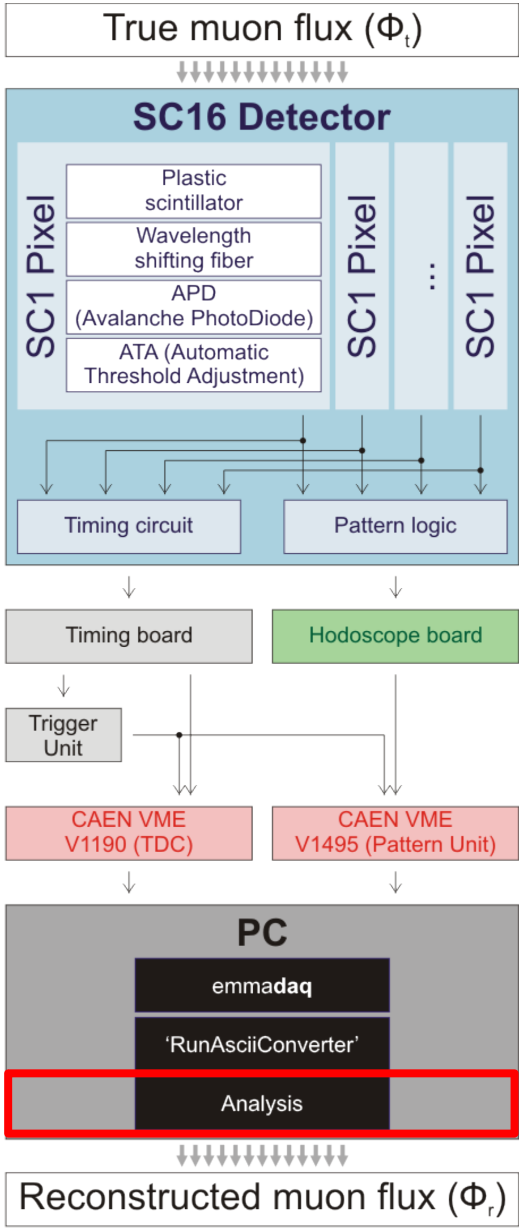
The core of data selection options:

→ **Read logbook**

=> **Skip bad runs** (ie. RMM117)

=> **Combine only similar runs**

→ same trigger, location, geometry, shielding, etc.



The core of data selection options:

→ **Read logbook**

=> **Skip bad runs** (ie. RMM117)

=> **Combine only similar runs**

→ same trigger, location, geometry, shielding, etc.

→ **Basic** quality cuts (in this order!)

=> Require both timing and pattern data for every SC16

→ If missing remove this SC16 from event **(do not remove the whole event)**

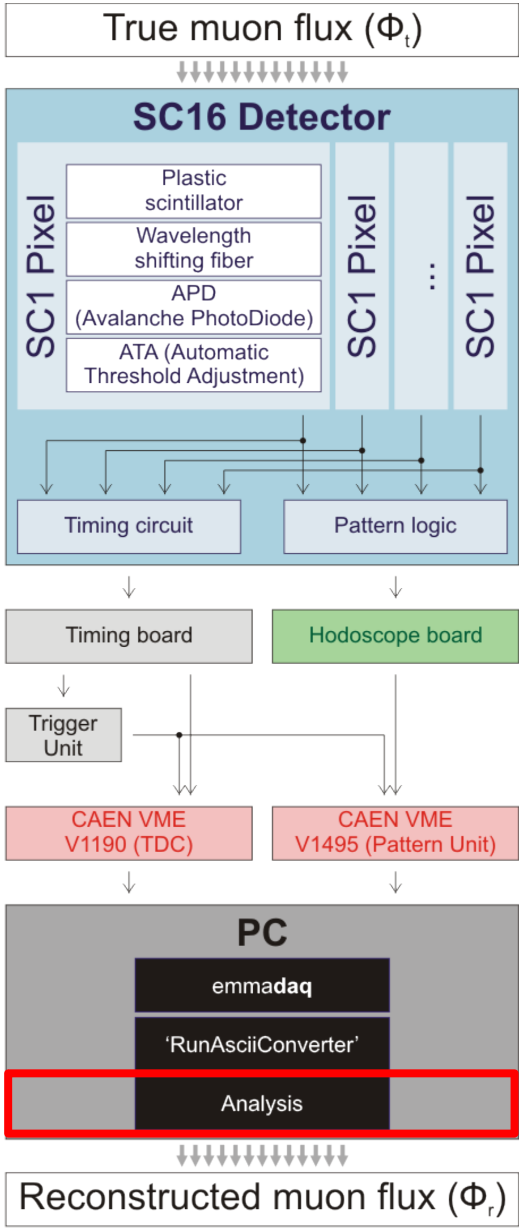
=> Apply time cuts

→ **Remove** SC16 from event if **Δt > 21 ns**

=> Δt = time difference between SC16 and average of the event

=> 21 ns = 10 ns (FWHM) + 11 ns (systematics)

=> **3-fold level coincidence** (Top & Middle & Bottom)

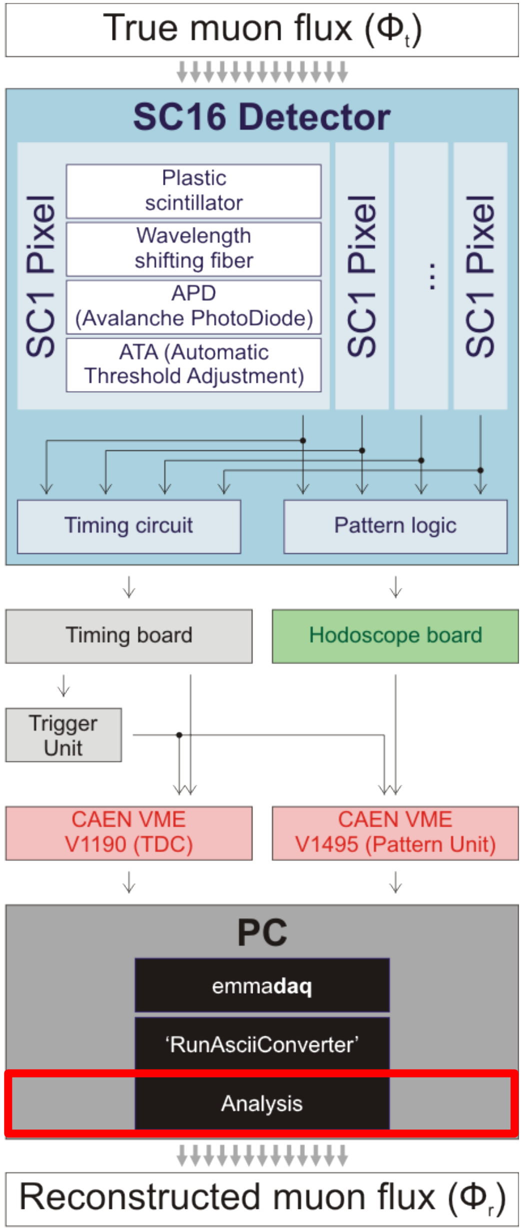


The core of data selection options:

→ **Read logbook**
  => **Skip bad runs** (ie. RMM117)
  => **Combine only similar runs**
    → same trigger, location, geometry, shielding, etc.

→ **Basic** quality cuts (in this order!)
  => Require both timing and pattern data for every SC16
    → If missing remove this SC16 from event
      (do not remove the whole event)
  => Apply time cuts
    → **Remove** SC16 from event if **Δt > 21 ns**
      => Δt = time difference between SC16
        and average of the event
      => 21 ns = 10 ns (FWHM) + 11 ns (systematics)
  => **3-fold level coincidence** (Top & Middle & Bottom)

→ **Extended** quality cuts:
  => Apply time calibration
    → **Δt < 11 ns** = 10 ns (FWHM) + 1 ns (systematics)
  => Use tracking
    → … huge topic …

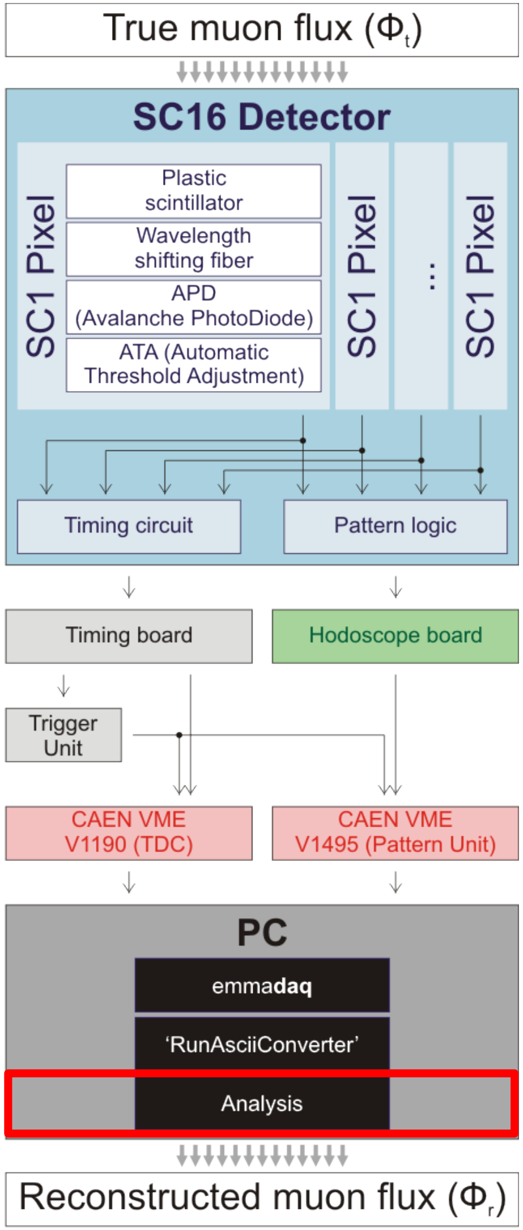


The core of data selection options:

→ **Convenience** (multiplicity per level) cuts (should not be needed, but simplify tracking):

=> MT=1 & MM=1 & MB=1

=> (MT≥1 & MM≥1 & MB≥1) & (MT≤2 & MM≤2 & MB≤2)



The core of data selection options:

→ **Convenience** (multiplicity per level) cuts (should not be needed, but simplify tracking):

=> MT=1 & MM=1 & MB=1

=> (MT≥1 & MM≥1 & MB≥1) & (MT≤2 & MM≤2 & MB≤2)

=> M≥3 → EAS (Extensive Air Showers, not single muons)

→ According to Timo's multiplicity plot: (see slide 6, Data Analysis Tasks – yesterday's talk)

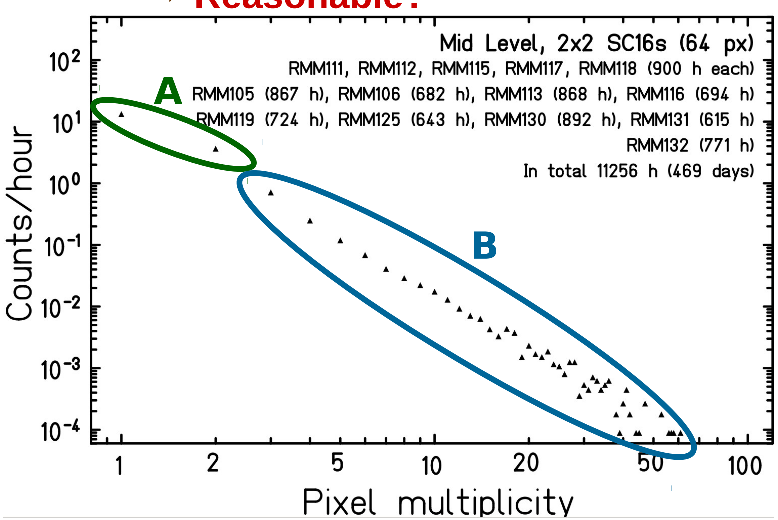
A = #(MM=1 & MM=2) = 13.7

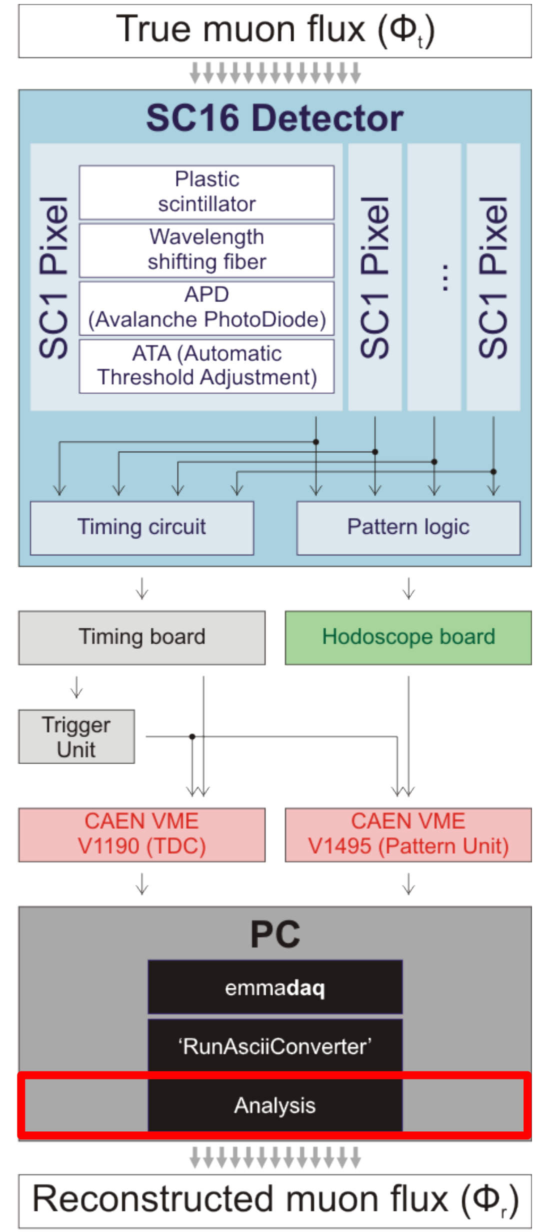
B = #(MM>2) = 1.14

Ratio B/(A+B) = 7.7 %

=> Ratio of the number all proper events vs. EAS events

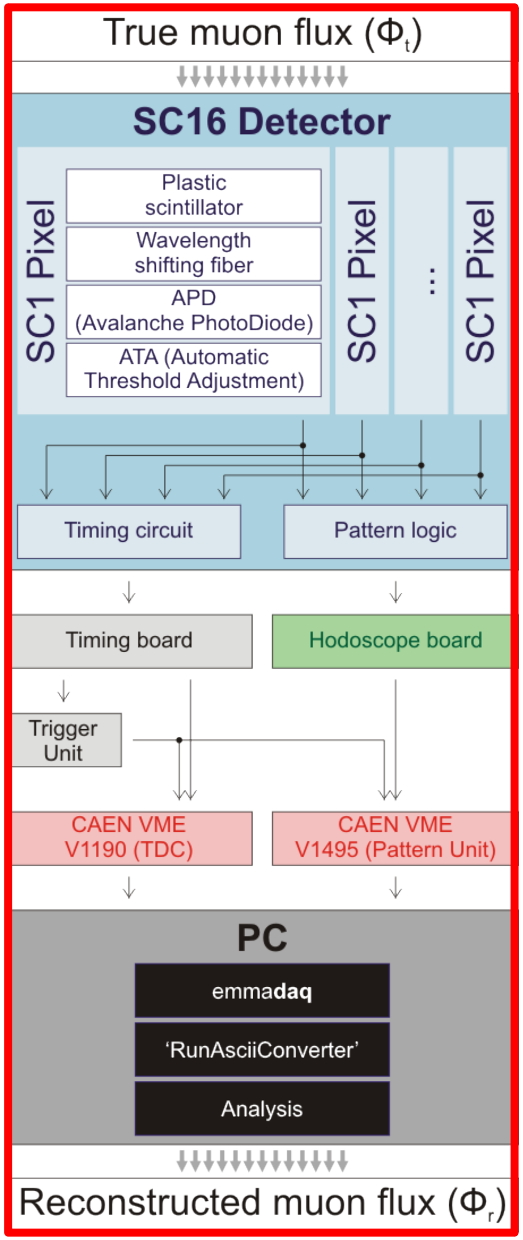
→ **Reasonable?**





Conclusions

Section of the system	Muon / event detection efficiency	Comment
Optical	100%	
APD	>>99%	→ Possible **minimal losses** due to threshold setting → very low energy muons lost
Timing chain	100%	
Pattern chain	≤99.9% >80%	→ Study dependence on HB channel → it seems there is none → Any **ideas** how to check it?
Trigger	>90%	→ Losses related to dead time => **Scaler** data → get **exact number**
emmadaq	100%	
Binary file reader and ASCII converter	~99%	→ Well known and controllable losses of data collection time → EOF problems → Check the acquisition times from every file
Analysis	?	→ Should be carefully investigated every time



Questions, comments?

Thank you for your attention