Performance measurements of triple GEM detectors in test beam

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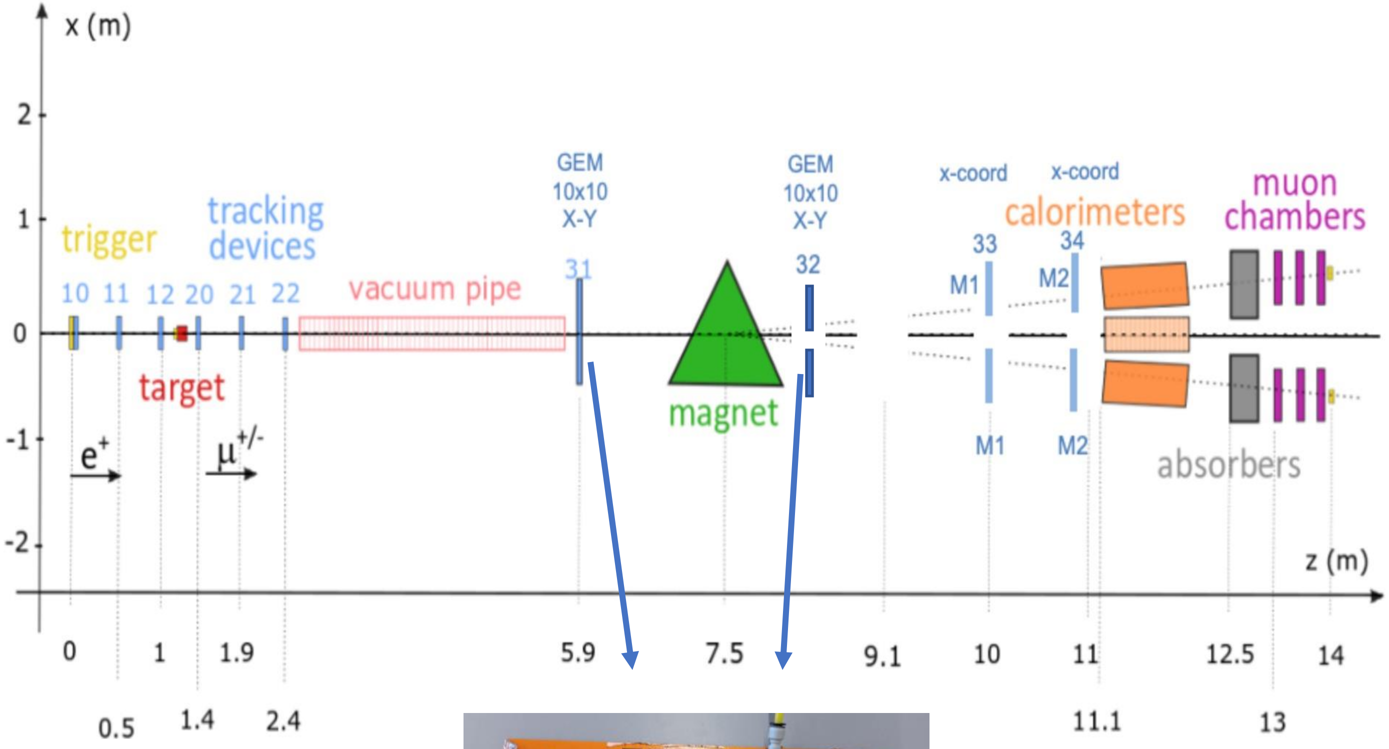
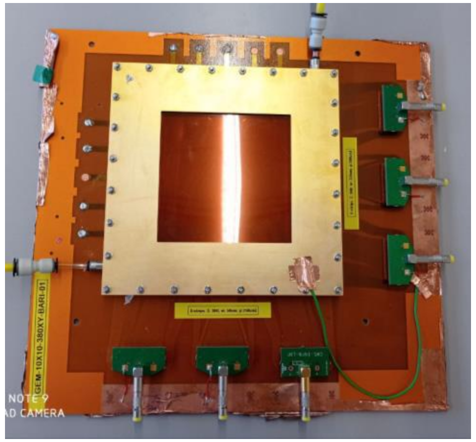
High res-triple GEM detector for LEMMA test beam

- **LEMMA** is a proposal for a scheme of production of muon beam at a future **Muon Collider**, delivering μ directly from e^+e^- interactions with **small emittance**.

- The LEMMA test beam has the **final goal** of
  - studying the **emittance** of the muon beam produced by a e^+ beam impinging on a fixed target and its **dependence** on the beam kinematic properties and the target features
  - measuring the muon production rate

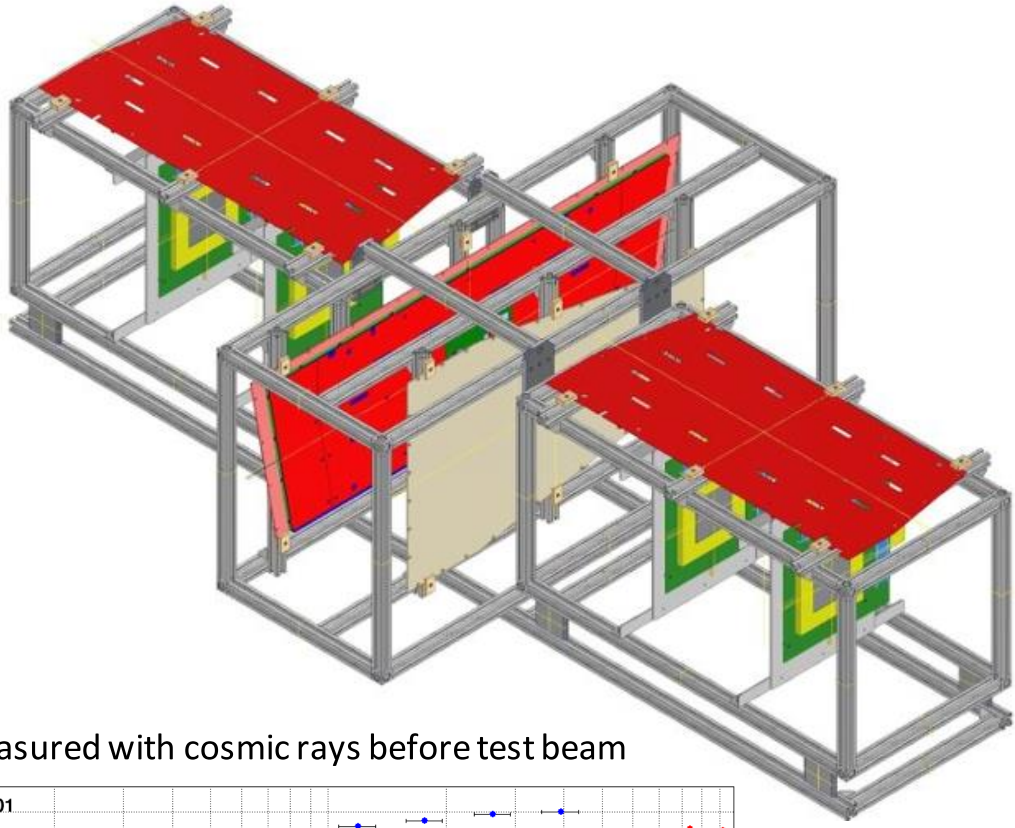


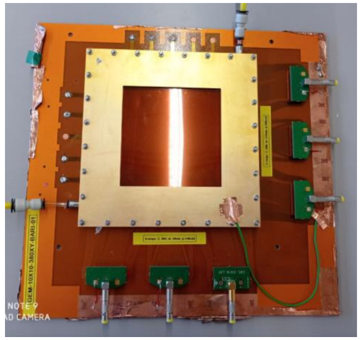
Precise muon **track reconstruction** is crucial to properly measure the $\mu^+\mu^-$ emittance -> include novel triple GEM detector with **high spatial resolution** in the muon arm

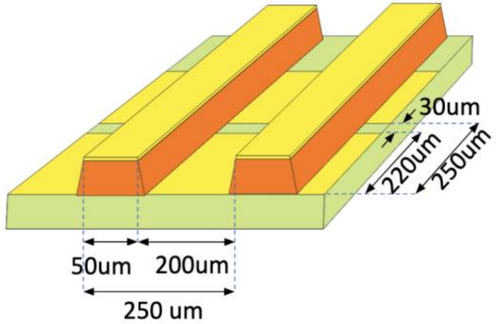


2021 GEM test beam

- The operation of the high resolution triple GEM detectors has been tested **for the first time** during the test beam in October 2021
- The test beam was helded in North Area at CERN using μ and π beam
- These detectors have been used as telescope for the beam tracking and the **efficiency** and **space resolution** have been measured.



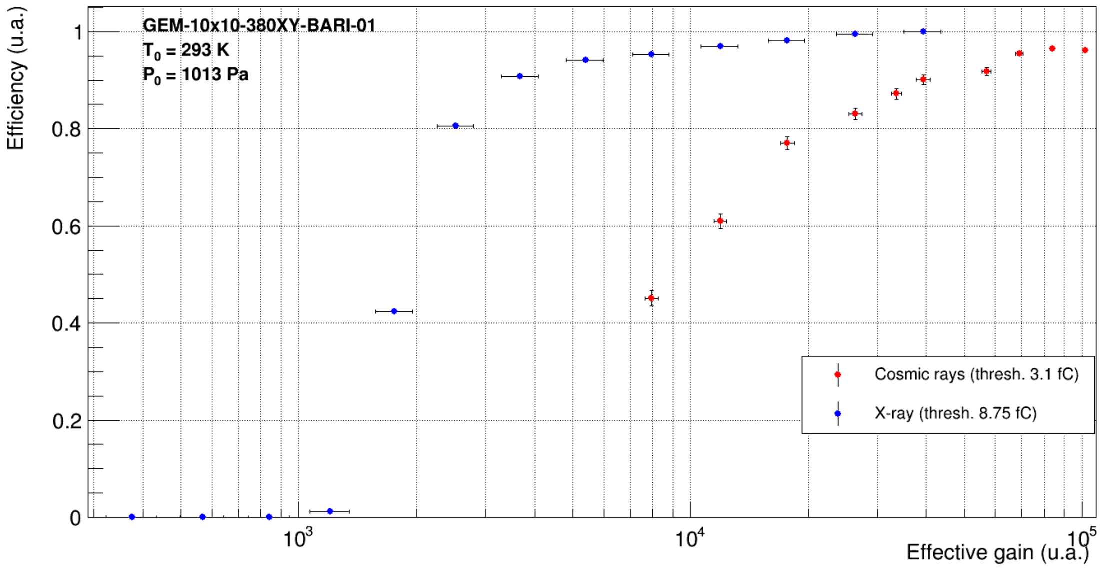




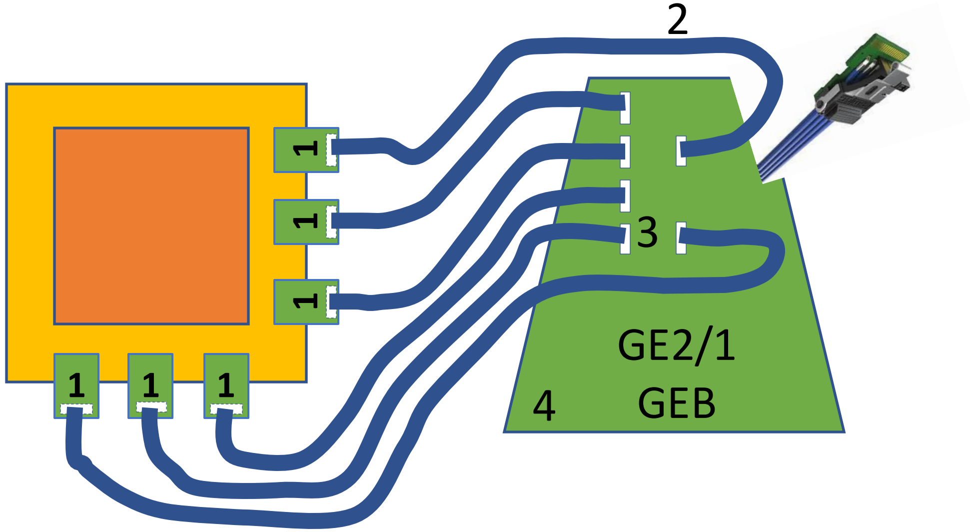
Tracker chamber readout strips

- **Four** 10x10 cm^2 **high-resolution** triple-GEMs
  358 strips, 250 μm pitch
  (expected space resolution **75 μm**)
- **Trigger: three-scintillator coincidence**
  (2 front + 1 back)

Efficiencies measured with cosmic rays before test beam



DAQ: Front-end electronics

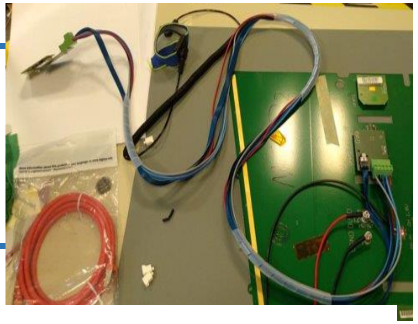


1 ***Front-end ASIC: VFAT3***

- *128 channels*
- *High sensitivity (45 mV/fC)*
- *0.5 MHz/strip rate capability*

VFAT3

2 ***Fire-Fly cables 1.5 m long*** for VFAT connection to tracking chambers to GEB



Fire-Fly cable

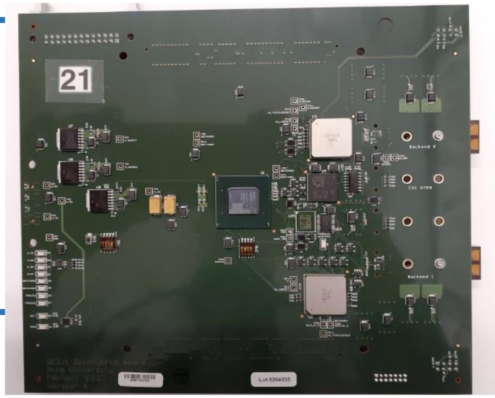
3 ***Plugin cards*** for VFAT connection to GEB

Plugin card

4 ***On-detector FPGA: OptoHybrid (Xilinx ARTIX-7) [CMS-TDR-013]***

3x (one per GEB)

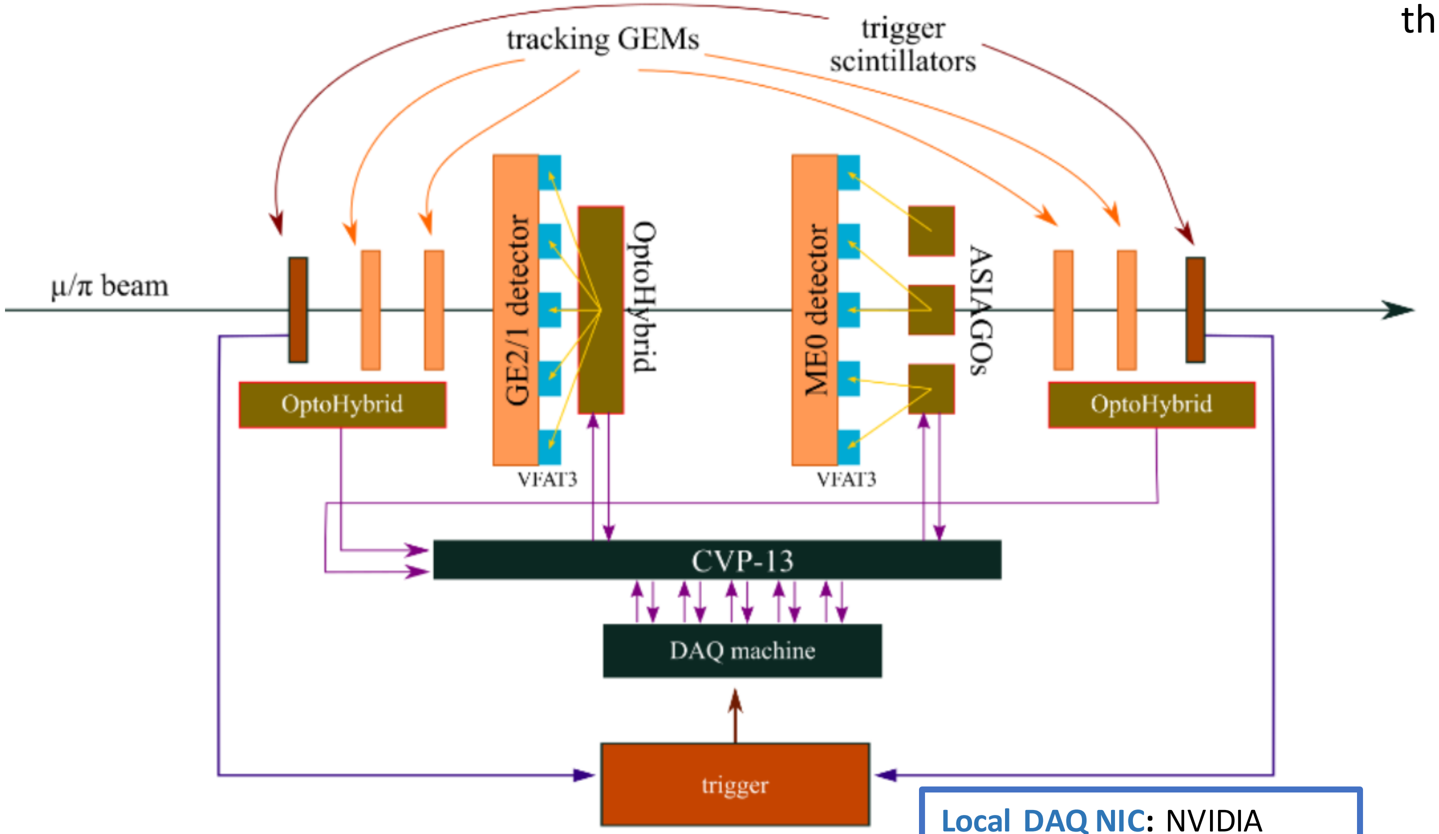
- *VFAT e-links to GBTx*
- VTRx + fibers to back-end
- VTTx to trigger lines (unused)



Optohybrid picture

DAQ: Back End

- All data sent to BE over optical links
- Custom PCIe back-end based on commercial FPGA
- 1 Gb/s Ethernet-based local readout on DAQ machine through additional network card



CVP-13 inside DAQ machine
+ **network card** (local DAQ)
+ water **cooling**

Back-end board:
CVP-13 commercial PCIe board with
VU13P FPGA

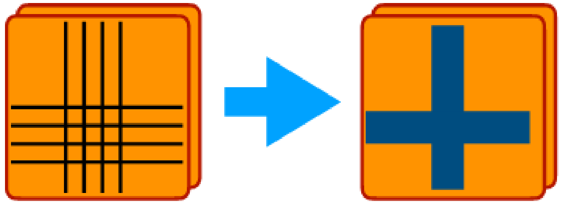
Local DAQ NIC: NVIDIA Mellanox MCX4121A-XCAT

SFP+ limit 10 \Gb/s

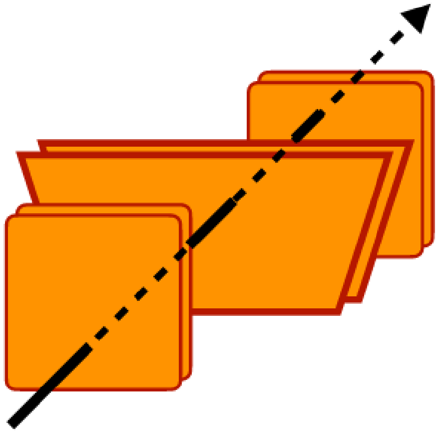
Reconstruction and analysis – Track building

1st step: **Unpack data** converting raw binary data to readable objects (Digi)

2nd step: Clusterize the digi information to construct RecHits (**Local reconstruction**)

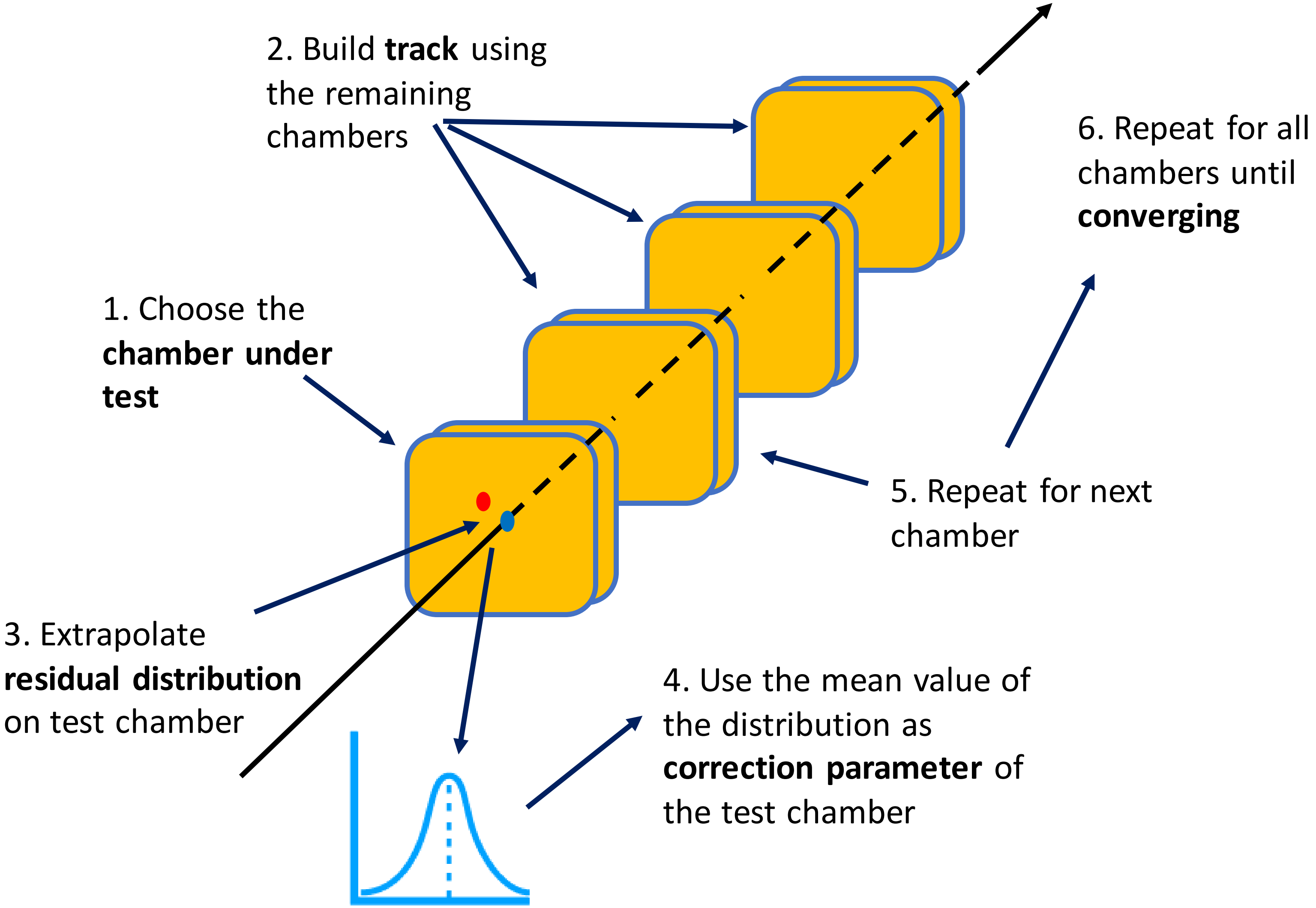


3rd step: **Build tracks** from the RecHits of each tracking chamber



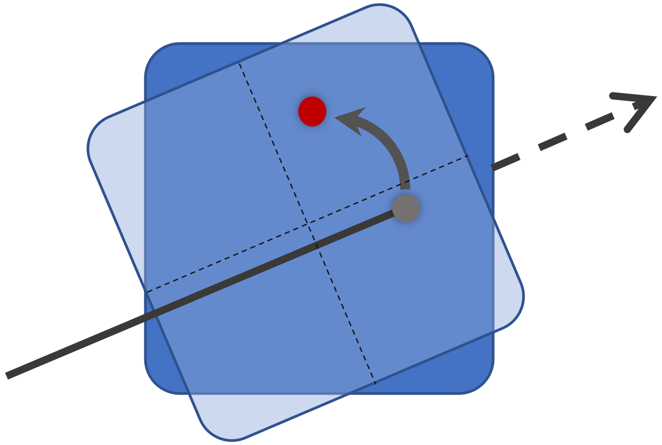
4th step: **Analyze tracks** to extract efficiency, residuals, etc.

Reconstruction and analysis – Transversal alignment



Reconstruction and analysis – Angular alignment

Iterative method similar to transversal alignment



Method: determining chamber misalignment from residuals vs propagated hit position.

Assuming x_{prop} is the correct value and x_{rec} is misaligned by θ,

$$\begin{cases} x_{\text{rec}} = x_{\text{prop}} \cos\theta - y_{\text{prop}} \sin\theta \\ y_{\text{rec}} = x_{\text{prop}} \sin\theta + y_{\text{prop}} \cos\theta \end{cases} , \qquad (1)$$

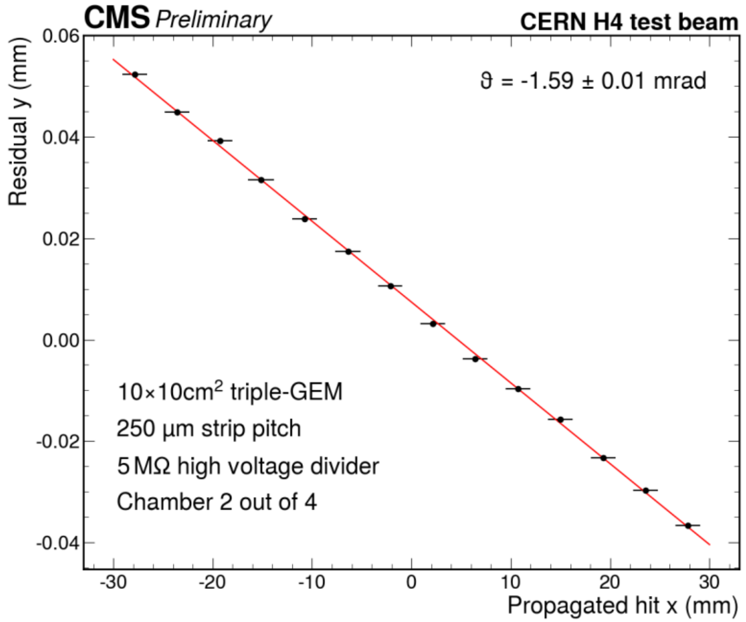
so

$$\begin{cases} \delta x = x_{\text{rec}} - x_{\text{prop}} = x_{\text{prop}}(\cos\theta - 1) - y_{\text{prop}} \sin\theta \\ \delta y = y_{\text{rec}} - y_{\text{prop}} = x_{\text{prop}} \sin\theta + y_{\text{prop}}(\cos\theta - 1) \end{cases} . \qquad (2)$$

Considering that

$$\cos\theta - 1 \sim O(\theta^2) \quad \text{while} \quad \sin\theta \sim O(\theta),$$

it is most sensitive to extract θ from the correlation of δx vs y_{prop} (or from δy vs x_{prop}).



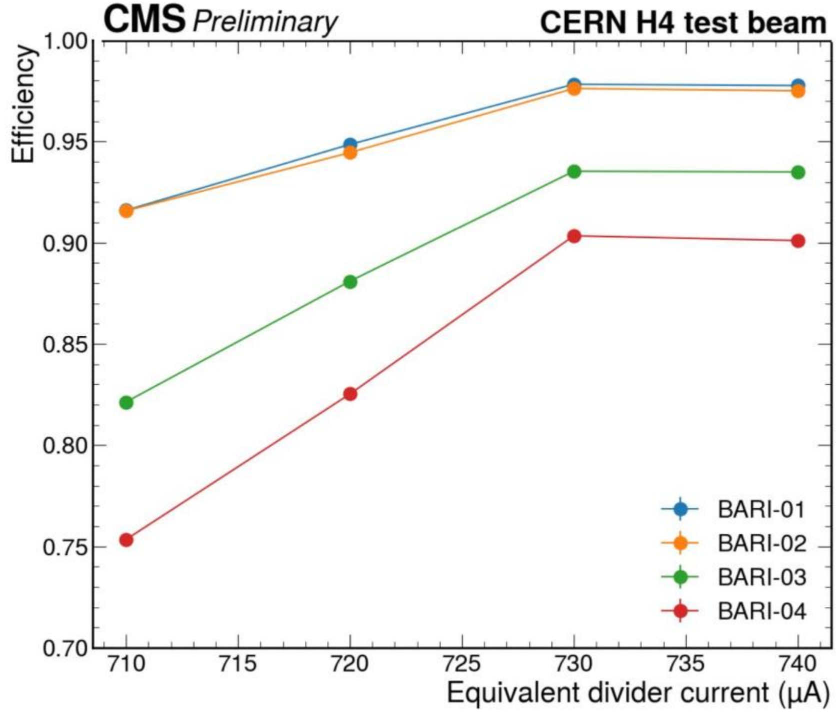
Triple GEM tracker performances – Efficiency

HV efficiency scan obtained by requiring that

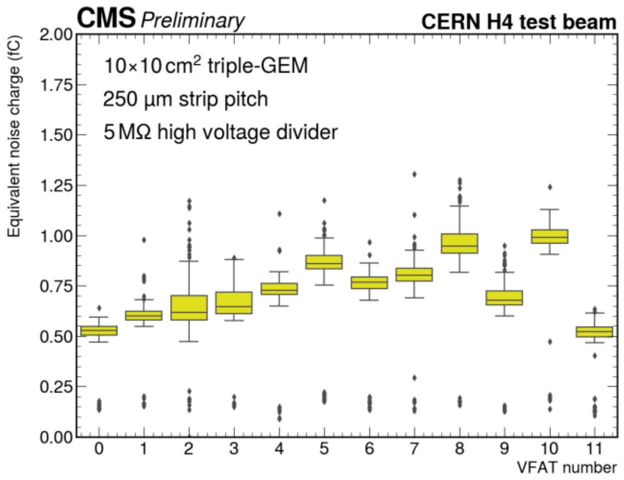
- The extrapolated hit of the track on the test chamber falls in the active area of the chamber
- The extrapolated hit matches a 2D reconstructed hit

Efficiency to muons between 90% and 100% for BARI-01 and BARI-02 operated at effective gas gain of 10^5

Lower efficiency for BARI-03 and BARI-04 operated at a lower effective gain



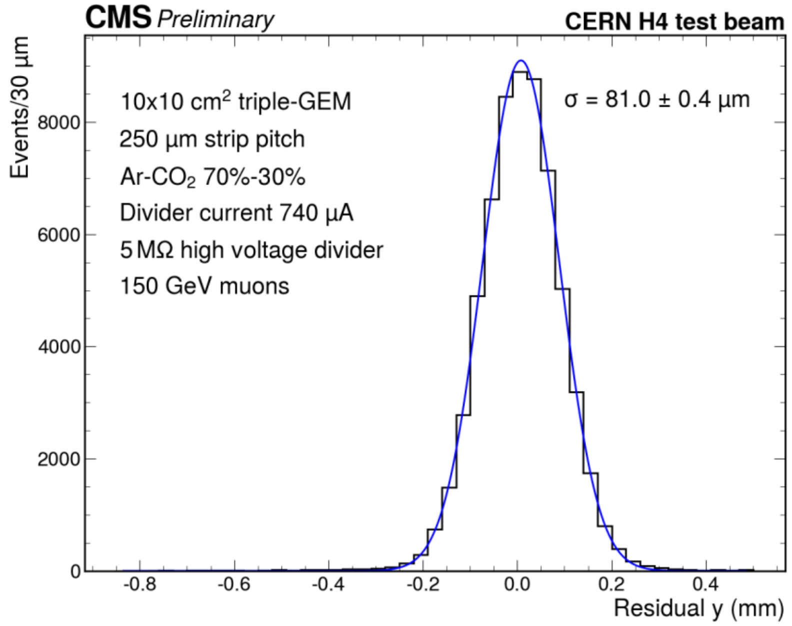
Main limitation due to **low signal to noise ratio**



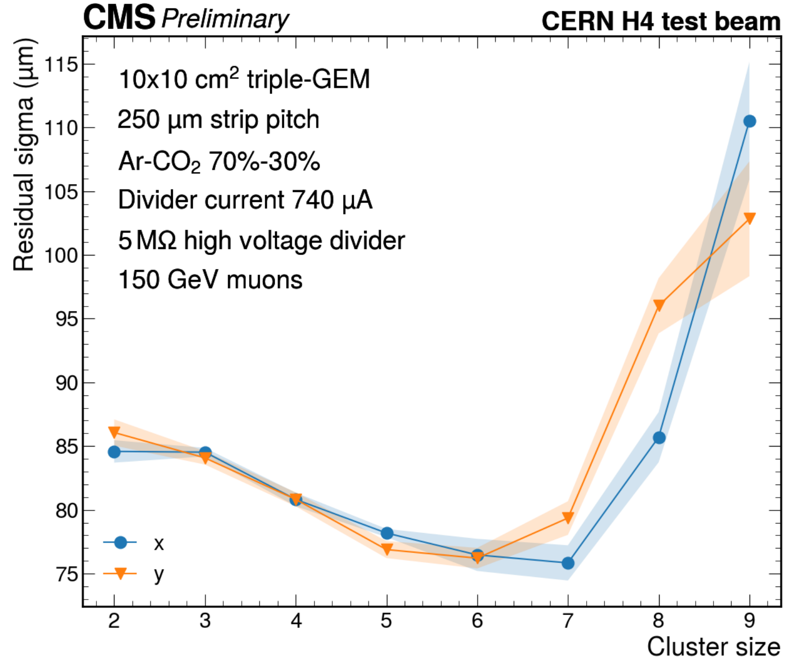
Triple GEM tracker performances – Space resolution

- Average space resolution of **81 μm** extracted from residual distribution
- Space resolution depends on cluster size:
    - At low cluster size: **low-charge clusters** reconstructed with wrong number of strips due to **high threshold**
    - At high cluster size: **asymmetric signal spreading** due to **delta rays** in single cluster

Residual distribution for tracking chamber 2 in y-direction for cluster size < 10



Space resolution of tracking chamber 2 vs cluster size



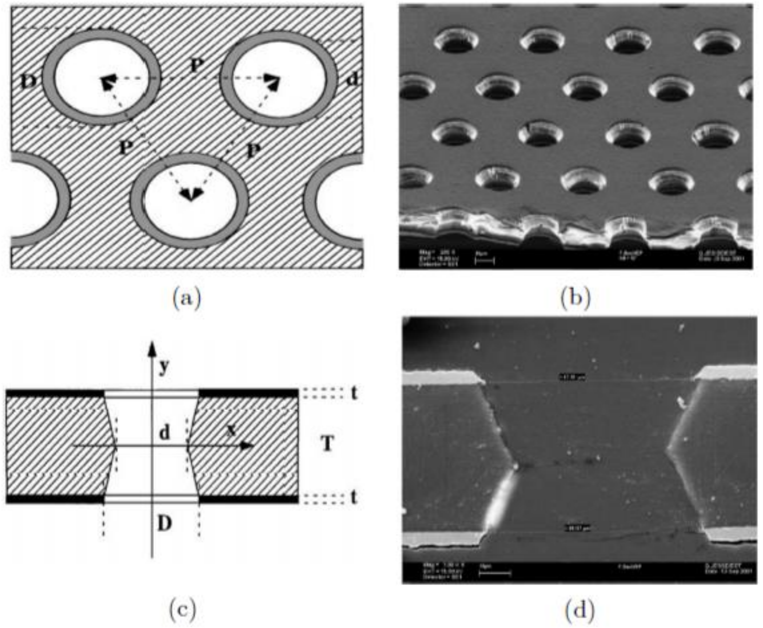
Conclusions and future plans

- The test beam aimed at measuring for the first time the performance of the new high resolution triple GEM detectors that formed the beam telescope
  - the efficiency, which has been found to be between the 90% and 100% for the chambers operated at higher gain
  - the space resolution, which measures around 81 μm
- The main limitations are related to the level of noise observed, that can be solved providing a custom grounding and shielding system to the detectors.

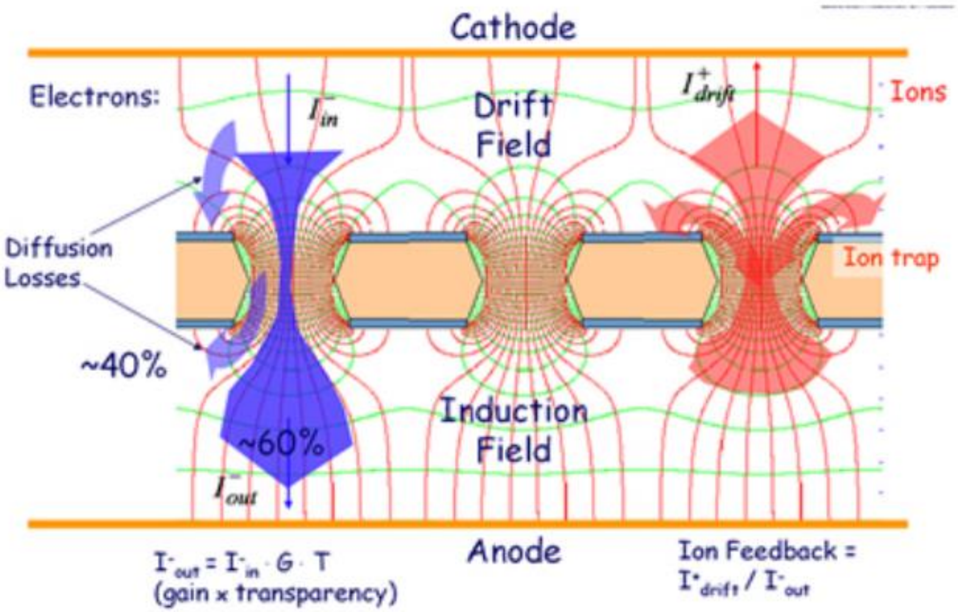
Backup

GEM Detector – Working principle

GEM foil



Single-GEM detector



MAP vs LEMMA production schemes

- The idea of a muon collider first developed in 1980s by a series of world-wide collaborations;
- Two major proposal with different outcome muon beam distinguished

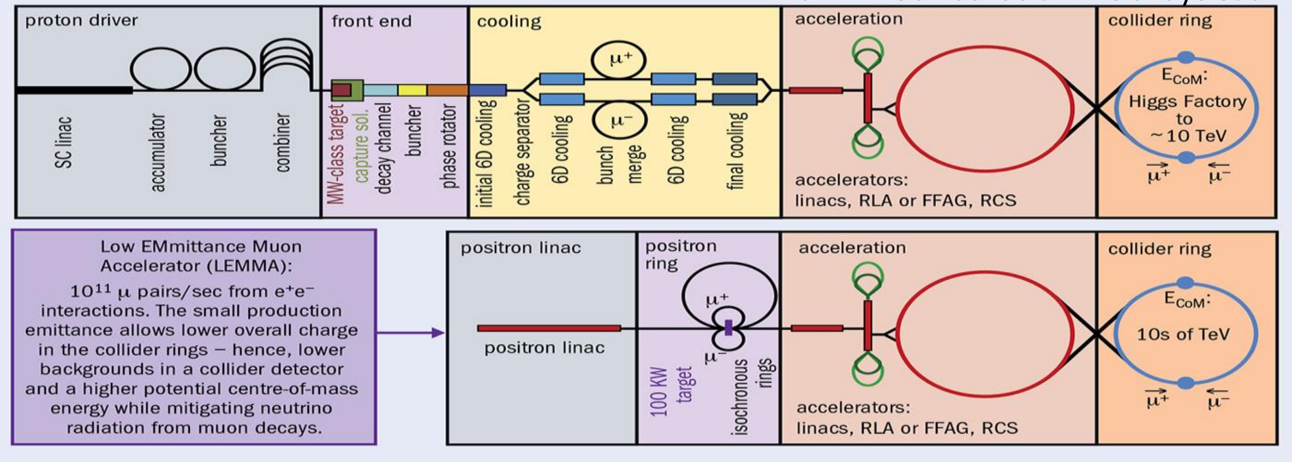
US Muon Accelerator Program (**MAP**), 2011

- **Proton** driver scheme, producing μ
  - as **tertiary** particles
  - at low energy
  - with **large emittance** -> needed a quick cooling and confinement

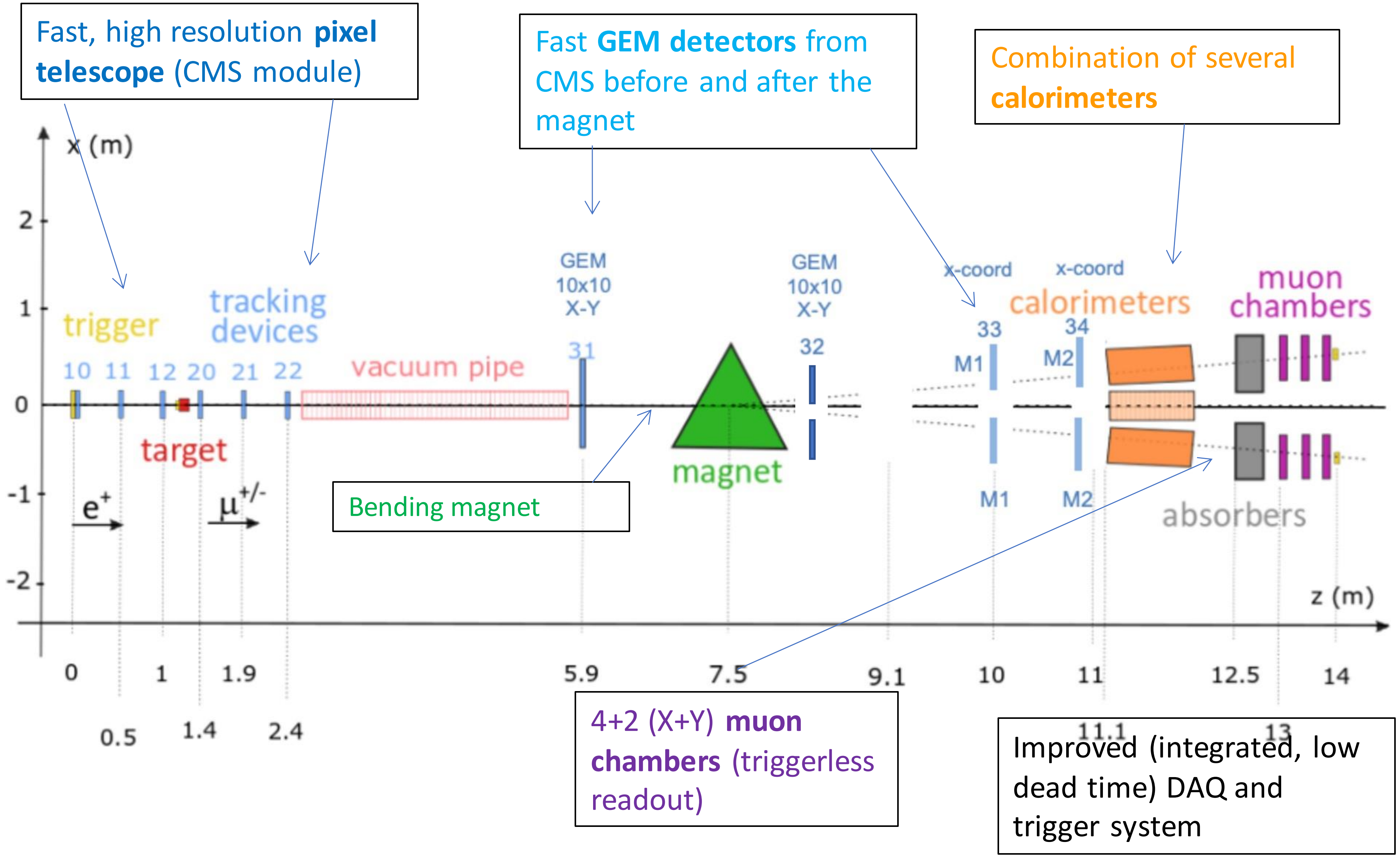
Low Emittance Muon Accelerator (**LEMMA**), 2013

- **Positron** driver scheme, producing μ
  - **directly** from $e^{+}e^{-}$ collisions
  - at ~ 22 GeV (t_{μ}~$500\ \mu s$ in lab. system)
  - with **small emittance** -> no cooling or confinement needed

arXiv: 1901.06150 J.P. Delahaye et al.

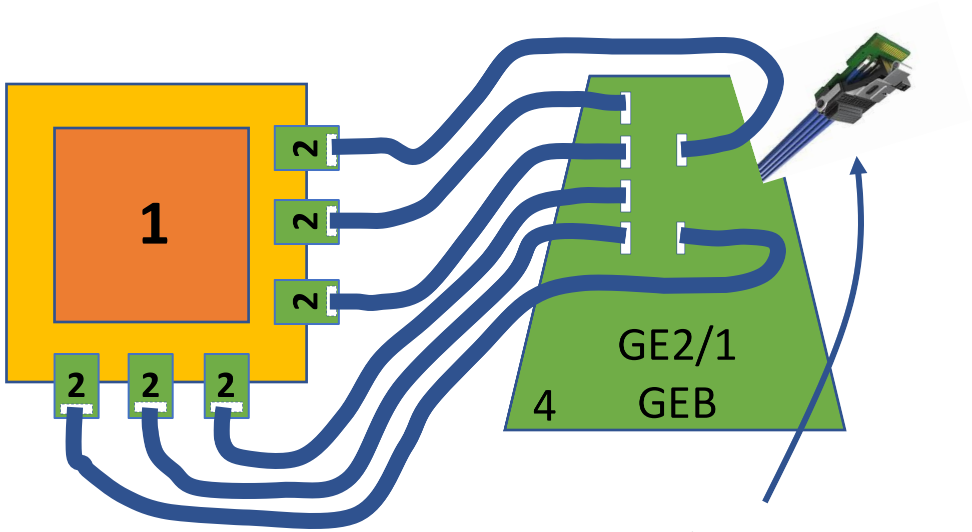


Scheme of the LEMMA test beam



Tracker noise level

Tracker detectors have still same basic design as 10-15 years ago …
Improvements made for GE21 and ME0 with shielding in ROB and GEB are very clear)



Frontend ASICs on 10x10
connected to “hanging” GEB by
Firefly cables (2 trackers/GEB)