Status of MUonE

U. Marconi

STRONG2020, 2021 November 26

The LO-HVP space-like

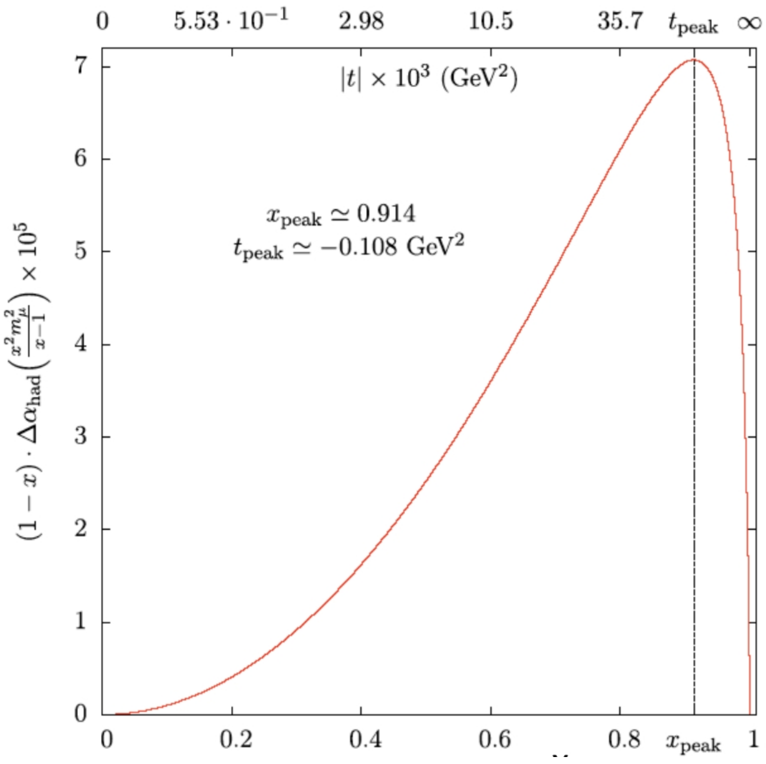
C.M. Carloni Calame, M. Passera, L. Trentadue, G. Venanzoni, Phys.Lett.B746(2015)325.

B.E. Lautrup, A. Peterman and E. de Rafael, Phys. Rep. C3 193 (1972)

E. de Rafael, Phys. Lett. B322 239 (1994).

$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 dx\,(1-x)\cdot\Delta\alpha_{had}\left(-\frac{x^2 m_\mu^2}{1-x}\right)$$

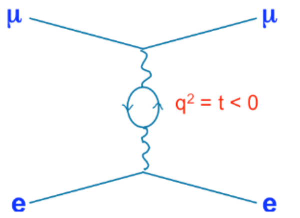
- **$\Delta\alpha_{had}$(t)** is the hadronic contribution to the **running of α(t)**, to be measured in the space-like region $t = q^2 < 0$.
- The integrand function is a **smoot function**: there are no resonances.
- Peak of the integrand at $x \cong 0.9$, $t = -0.11$ GeV^2, **$\Delta\alpha_{had}(t_{max}) \sim 10^{-3}$**



The MuonE proposal

Eur. Phys. J. C77(2017)139

- Elastic scattering **$\mu + e \rightarrow \mu + e$** with **$E_\mu$ = 160 GeV** muons colliding on atomic electrons of a fixed target of low Z.
- High intensity **CERN M2** muon beam: 5 x 10^7 μ/s
- **The shape of the angular differential cross section** is used to measure **$\Delta\alpha(t)$**.
  $\Delta\alpha_{had}(t)$ subtracting **$\Delta\alpha_{lep}(t)$** to **$\Delta\alpha(t)$**
  a_μ^{HLO} using the space-like approach.
- **Higly boosted final states** produced in the collisions: 0 < -t < 0.161 GeV^2 , 0 < x < 0.93
  The **angular range** in the order of the mrad.
- For **E_μ = 160 GeV** the **phase space covers 87% of the integral**. Smooth extrapolation to the full integral with a proper fit model seems possible.

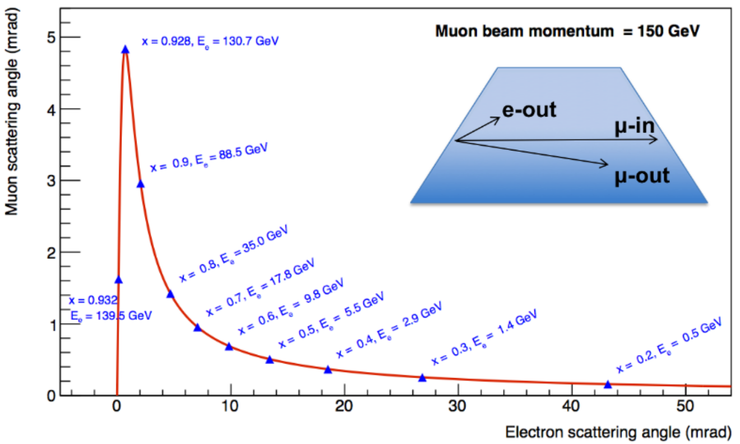


of α

$$\frac{d\sigma}{dt} \approx \frac{d\sigma_0}{dt}\left|\frac{\alpha(t)}{\alpha(0)}\right|^2 \approx \frac{d\sigma_0}{dt}\left|\frac{1}{1-\Delta\alpha(t)}\right|^2$$

$$\Delta\alpha(t) = \Delta\alpha_{lep}(t) + \Delta\alpha_{had}(t)$$

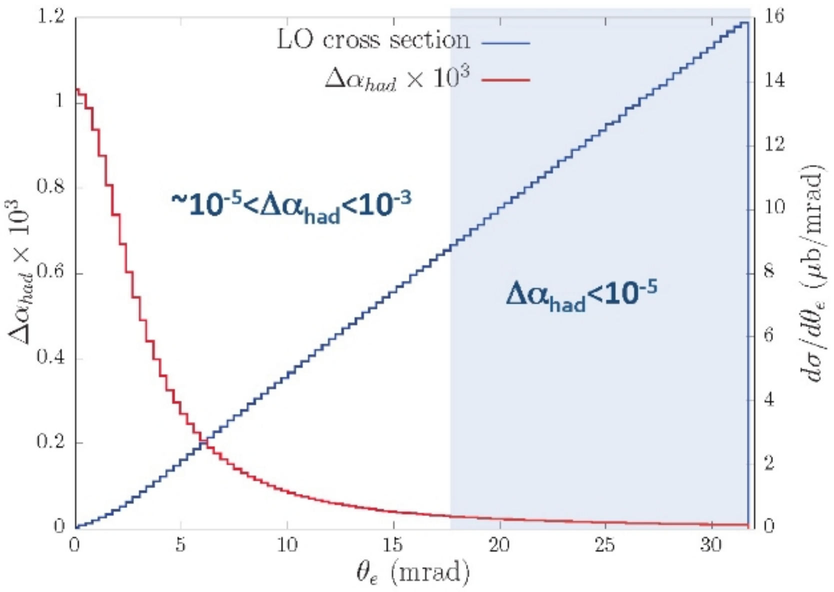
Scattering angles



Main features of the elastic process

The LO differential cross section is in blue.

The hadronic contribution to the running as a function of the electron scattering angle: Effects are relevant for small electrons scattering angles

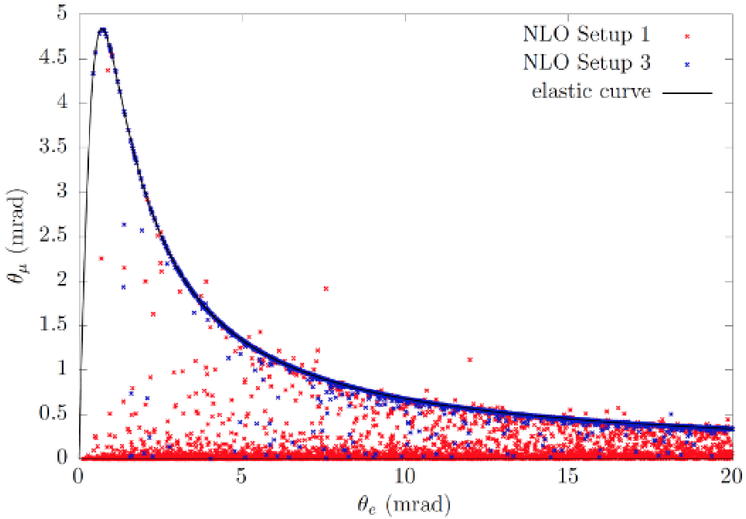


$$\frac{d\sigma}{dt} = \frac{4\pi\alpha^2}{\lambda(s, m_e^2, m_\mu^2)}\left[\frac{(s - m_e^2 - m_\mu^2)^2}{t^2} + \frac{s}{t} + \frac{1}{2}\right]$$

$$\frac{d\sigma}{dt} = \frac{d\sigma_0}{dt}\left|\frac{\alpha(t)}{\alpha(0)}\right|^2 \qquad \alpha(t) = \frac{\alpha(0)}{1 - \Delta\alpha(t)}$$

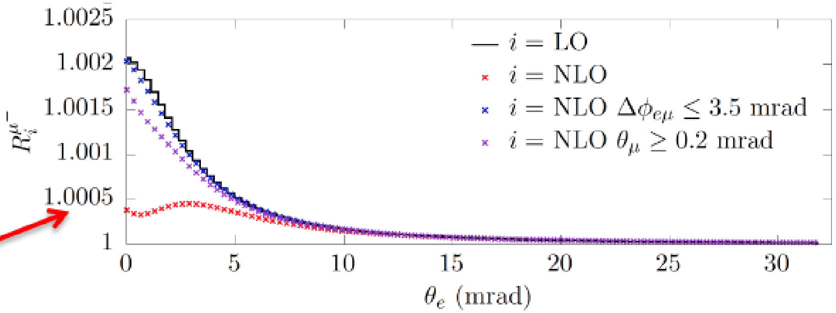
$$\Delta\alpha(t) = \Delta\alpha_{lep}(t) + \Delta\alpha_{had}(t)$$

NLO and elastic selection

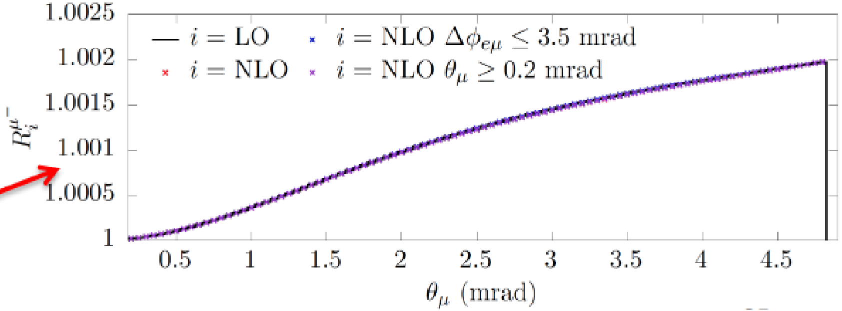


[M.Alacevich et al, JHEP02(2019)155](#)

NLO Setup 1 is the inclusive selection (no cuts)
Setup 3 has an acoplanarity cut $|\pi-(\phi_e-\phi_\mu)|<3.5$ mrad



Without any selection the signal sensitivity of the electron angle is destroyed -> necessary to implement an "elastic" selection

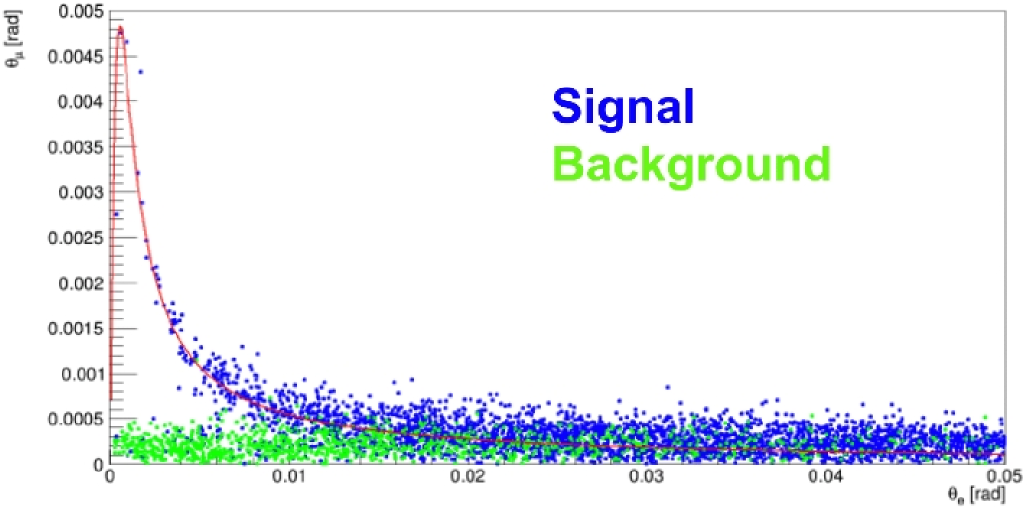


Instead the muon angle is a robust observable, stable w.r.t. radiative corrections -> it can be used with an inclusive selection (theoretically advantageous)

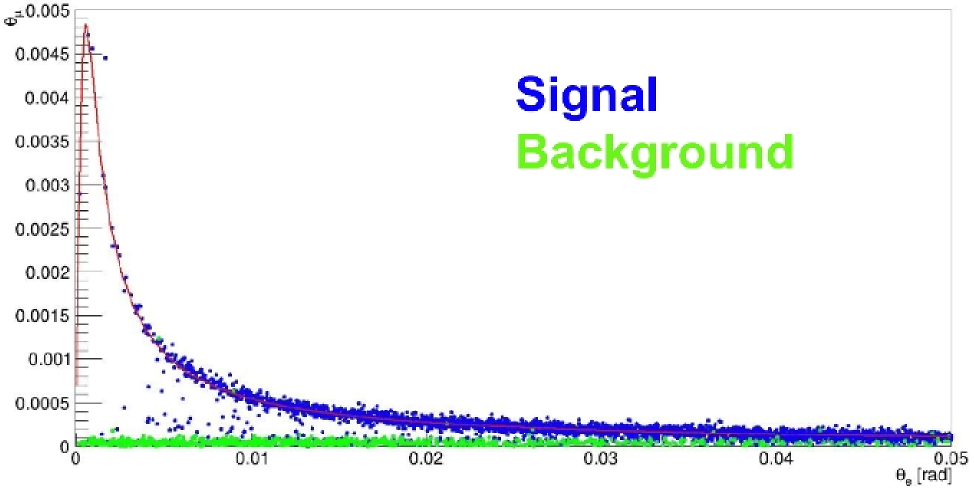
Role of the silicon strip detector intrinsic resolution

GEANT4 simulations

Resolution 40μm



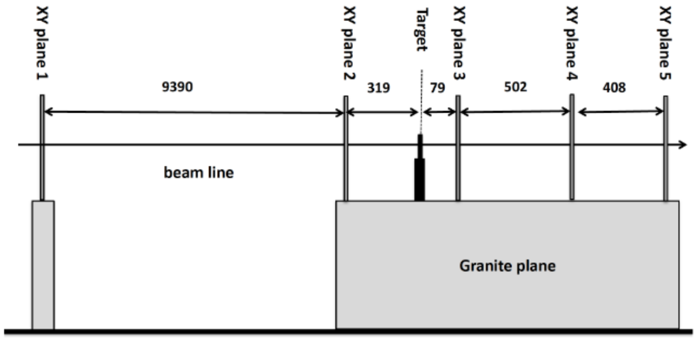
Resolution 10μm



MCS studies: beam tests at CERN

JINST 15(2020) P01017

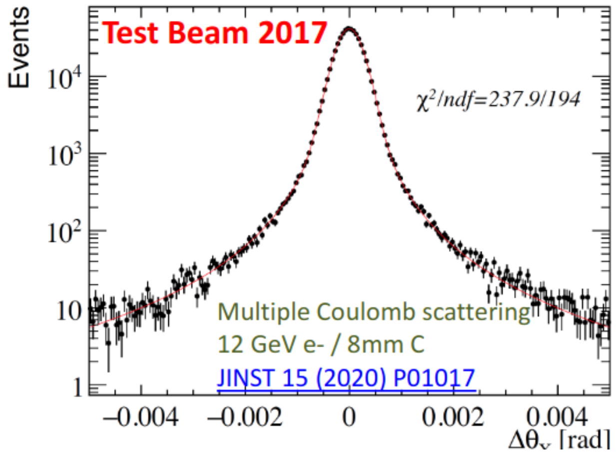
Adapted UA9 detector at CERN H8 Beam Line
Hit resolution 10 μm

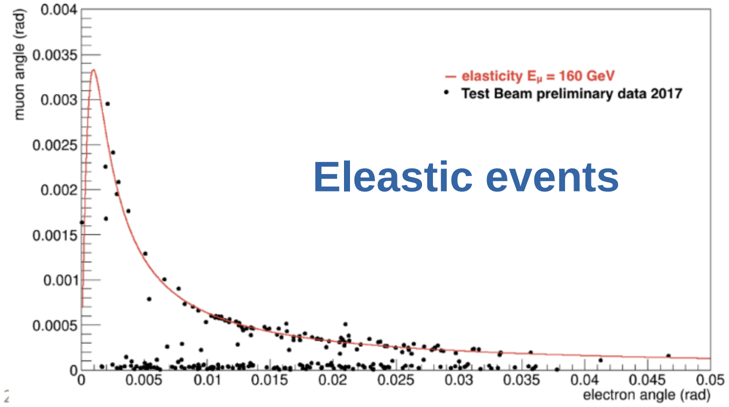


Evidence for μe elastic scattering with μ beam with E=160 GeV

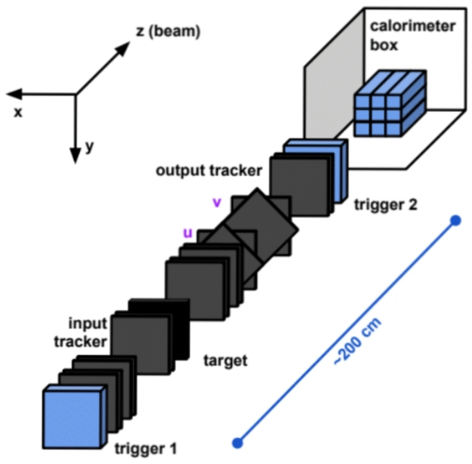
Golden Selection: single track in, two tracks out

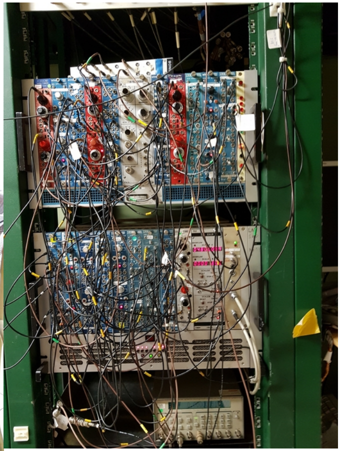
MSC effects: agreement to 1%



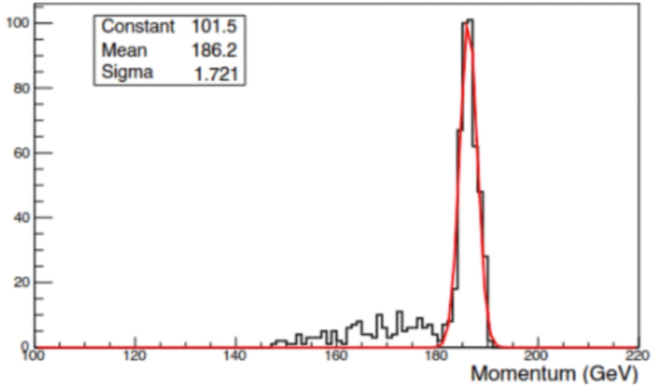


TB2018: at low counting rate





Muon momentum peaked at 187 GeV

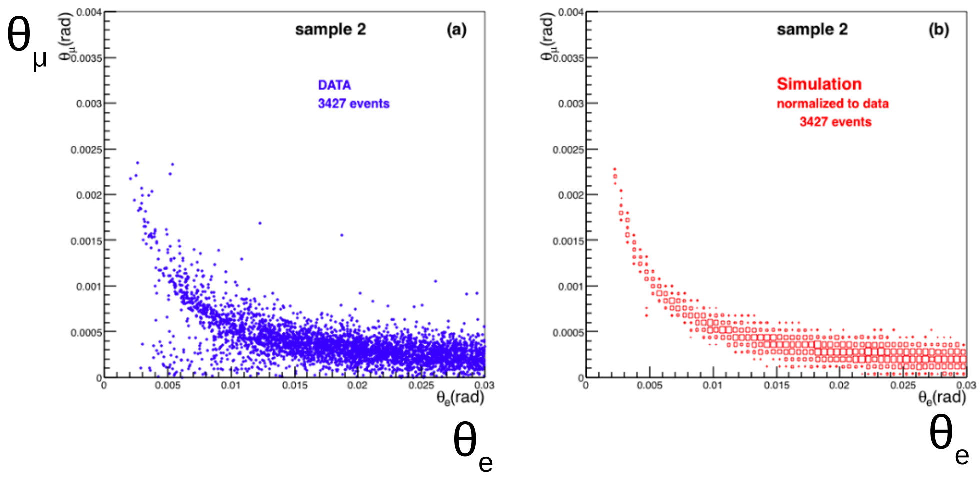


The Detector was located downstream COMPASS
Muons came from 190 GeV pions decaying in flight.
1m thick W filter installed to get rid of residual pions
Counting rate below **10 kHz**
Sensor hit resolution ~ **40 µm**

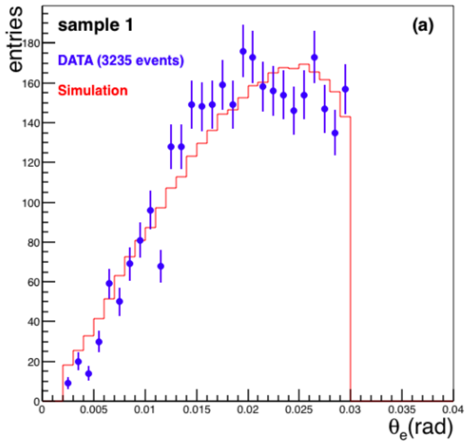
TB2018 data analysis

- **A study of muon-electron elastic scattering in a test beam. arXiv2021.11111, https://arxiv.org/pdf/2102.11111.pdf**
  Published by **JINST**

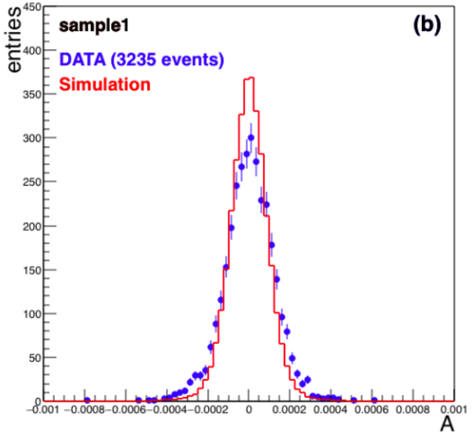
Correlation plots



Emission angle

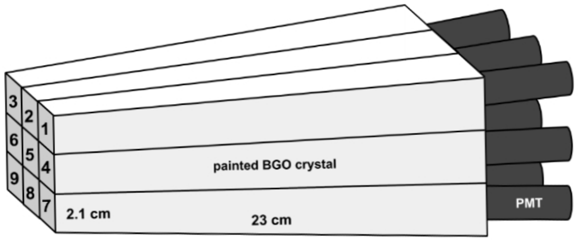


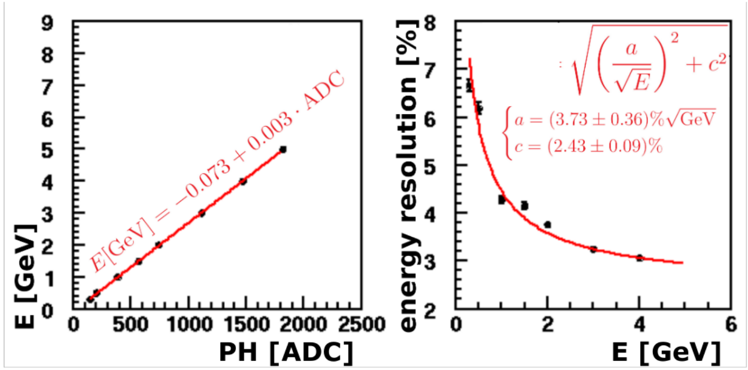
Acoplanarity

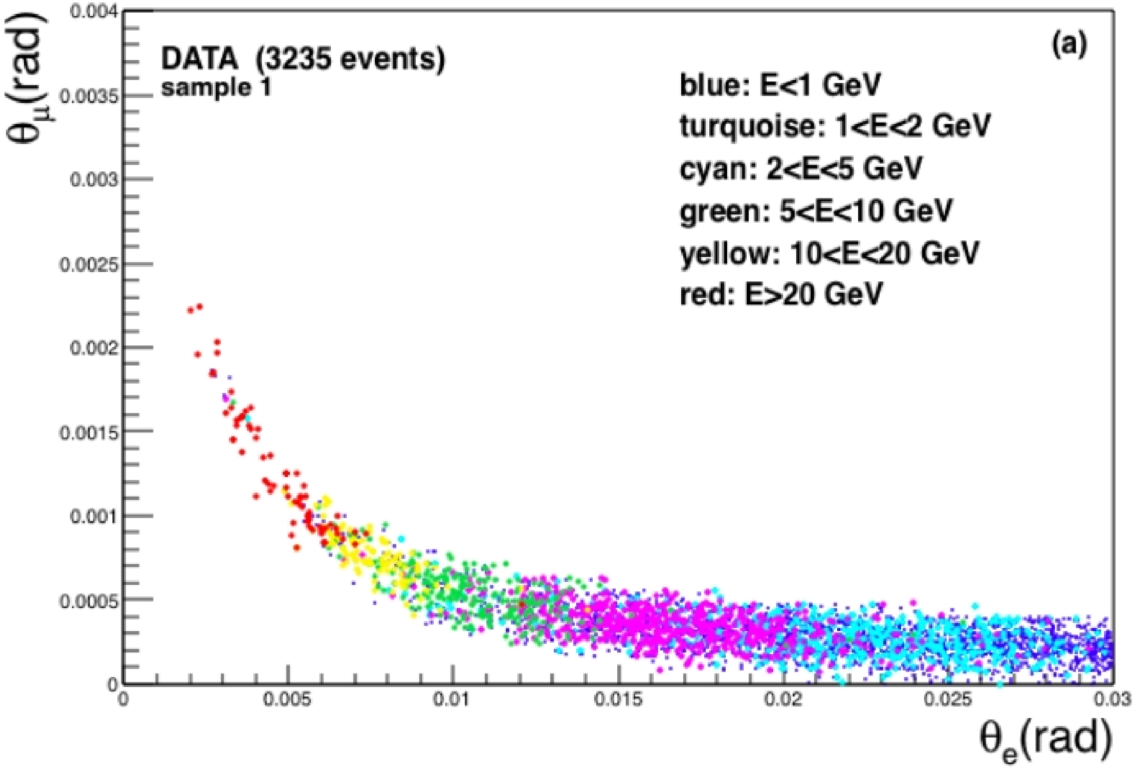


- We have been able to select a clean sample of elastic events. The background description deserves a dedicated study.

TB2018 data analysis





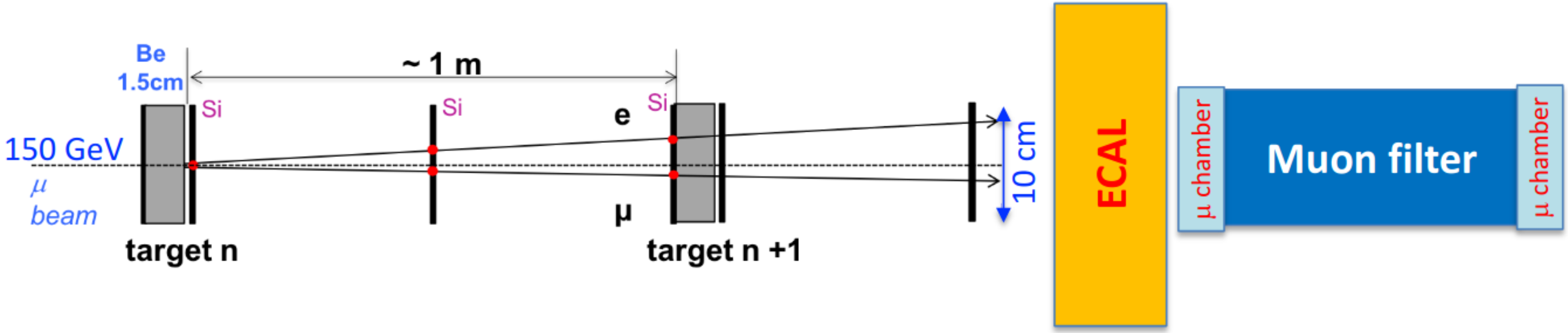


BGO tapered crystals, obtained by machining bigger spare blocks of the L3 endcap calorimeter

Detector layout

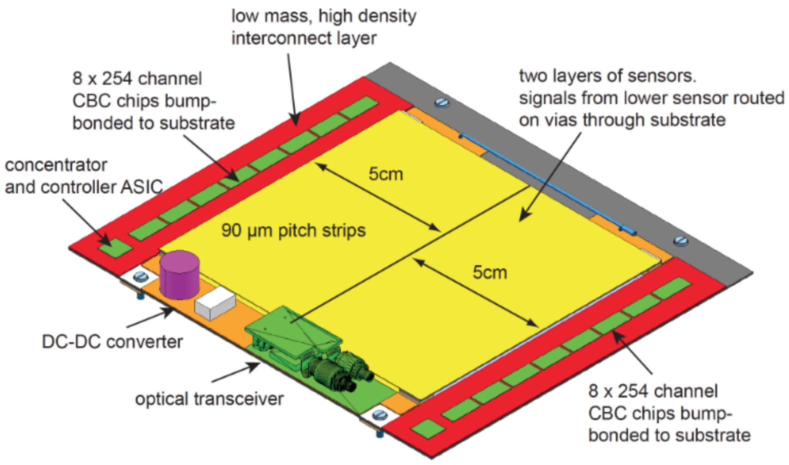
Letter of Intent SPSC-I-252

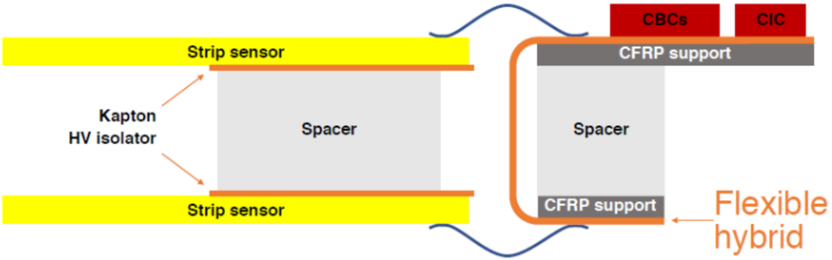
- Boosted kinematics: θ_e <32mrad (for E_e>1 GeV), θ_μ<5mrad
  The whole acceptance can be covered with 10x10cm² silicon sensors.
- Minimal distortions of the outgoing e/μ trajectories and small rate of radiative events with thin targets of low Z material.
- Modular structure of ~40 independent tracking stations, with targets material equivalent to 60cm Beryllium.
- ECAL and Muon filter after the last station, for PID and background rejection.



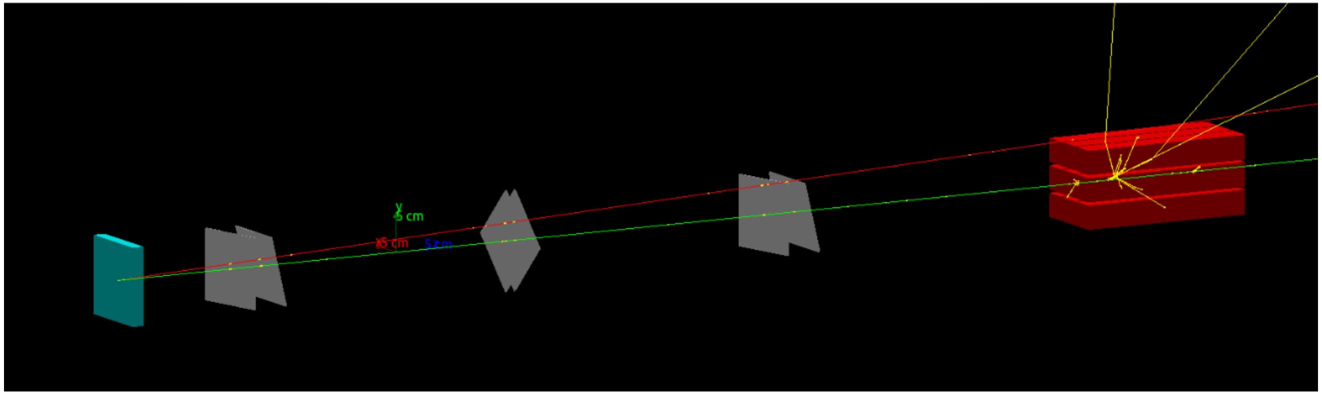
The silicon strip detector

- 2S modules, designed for the upgrade of the CMS tracking system
- A 2S modules consists of paired strip sensors to provide **stubs at 40MHz**
- Sensor’s pitch is 90µm, their thickness is 320µm. A modules is twice as thick.
- Distance bewteen sensors 1.8mm
- 16 CBC chips, each reading 254 strips: 127 of the top and 127 of bottom sensc Binary readout.





Rotating the 2S sensors



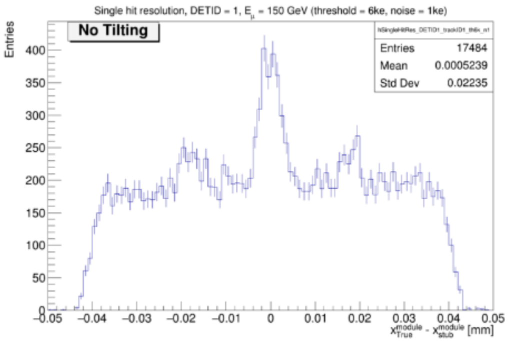
With a pitch of 90μm and the strip digital readout the expected resolution of a single sensor layer for single-strip cluster is **90/sqrt(12) ≅ 26μm**

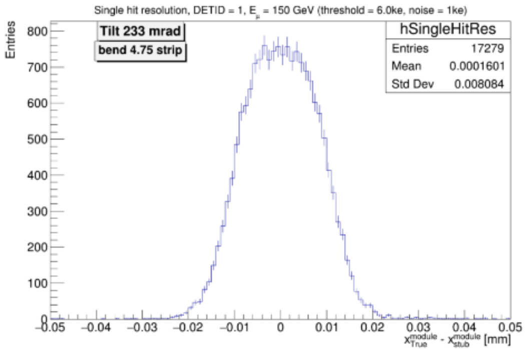
Rotating a sensor around an axis parallel to the strips direction improves the hit resolution.

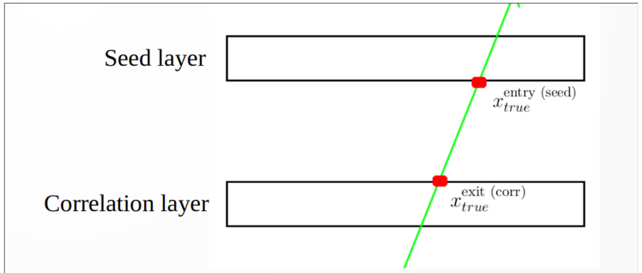
Optimal performance is obtained when **<cluster width> ~ 1.5** (same number of clusters made of 1 or 2 strips) for a **tilt angle ~14 degrees**

Further improvement by a small tilt of 25mrad, which is equivalent to an half-strip staggering of the two sensor layers of a 2S module

Sensors’ tilted geometry







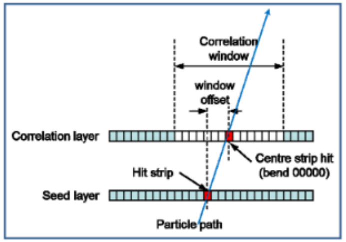
$$x_{stub} = \frac{x_{seed} + x_{corr}}{2} \qquad \text{bend} = x_{corr} - x_{seed}$$

$$x_{stub} = x_{seed} + \frac{\text{bend}}{2}$$

Final resolution:
22 µm → 8-11 µm

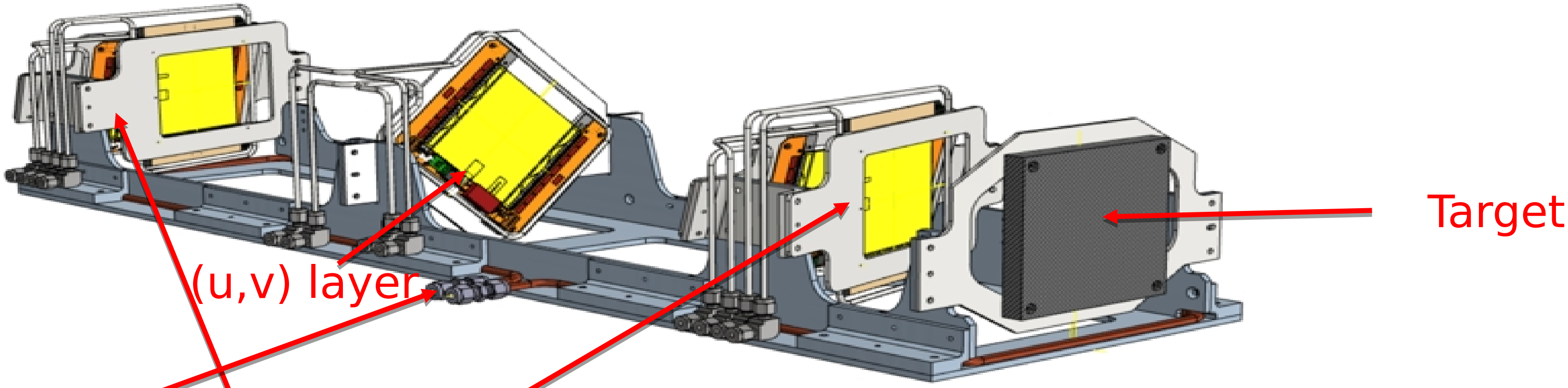
2S stubs at 40 MHz

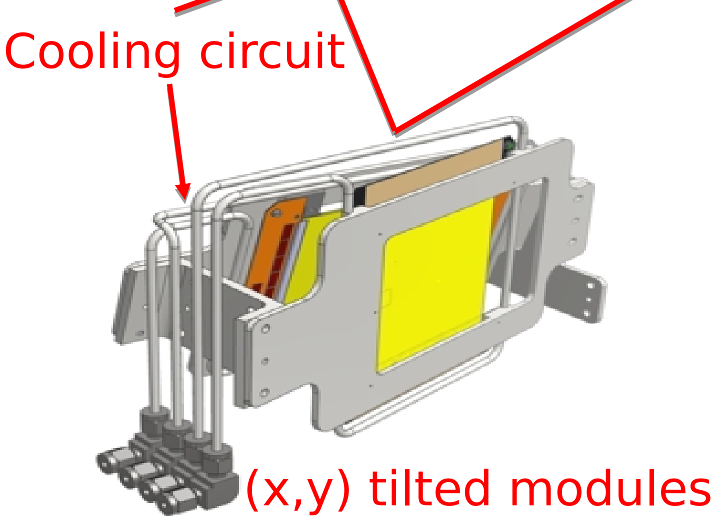
measured coordinate (x) determined by hit position on one layer and direction of the track stub



Tilt angle [mrad]	<bend> [strips]	threshold [σ]	resolution [µm]	<cluster width> [strips]
210	4.25	5	7.8	1.51
221	4.5	5.5	11.5	1.51
233	4.75	6	8.0	1.50
245	5	6.5	11.2	1.51
257	5.25	7	8.7	1.50
268	5.5	7.5	11.0	1.49

Tracker station

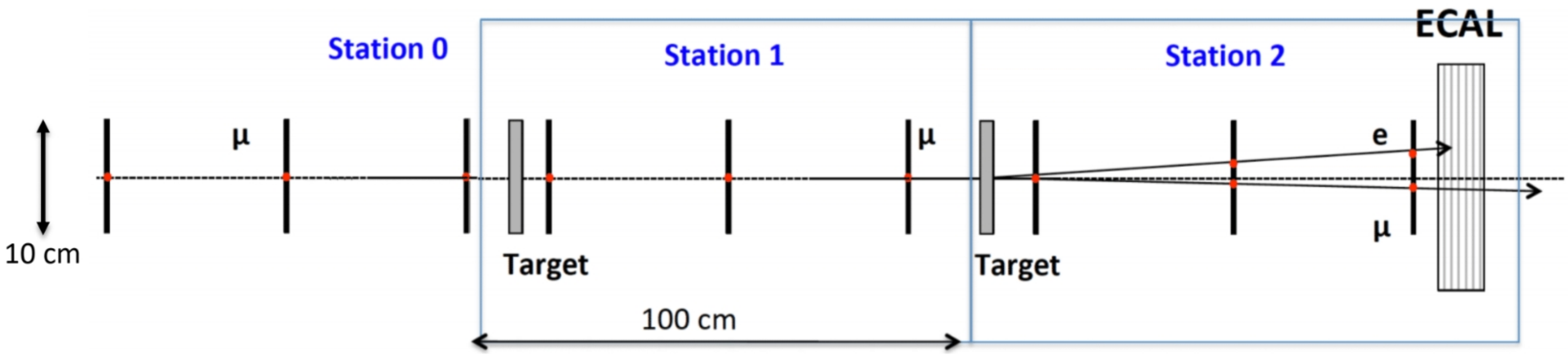




- (x,y) modules tilted with respect to the strip axis
- (u,v) central modules rotated to resolve ambiguities

- High mounting precision and mechanical stability required
- Low thermal expansion coefficient material: Invar, CTE = 1.2×10^{-6} K^{-1}
- Cooling circuit foreseen to control temperature

Detector prototype to be tested



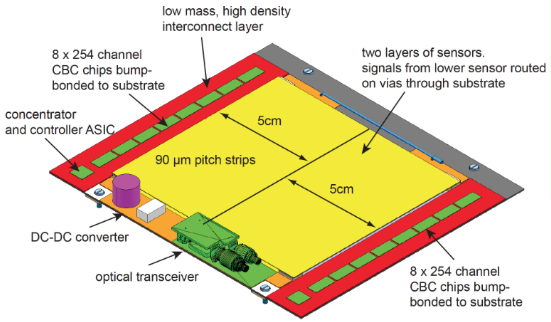
At the M2 beamline, upstream of the COMPASS detector, after its BMS

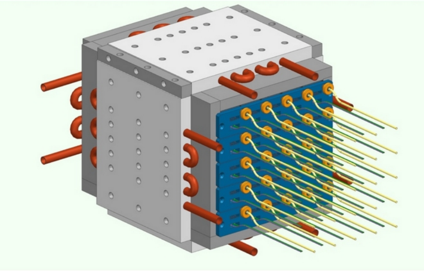
Check the FEE and the DAQ system.

Confirm system engineering:
check mechanical and thermal stability.

Test alignment procedures.

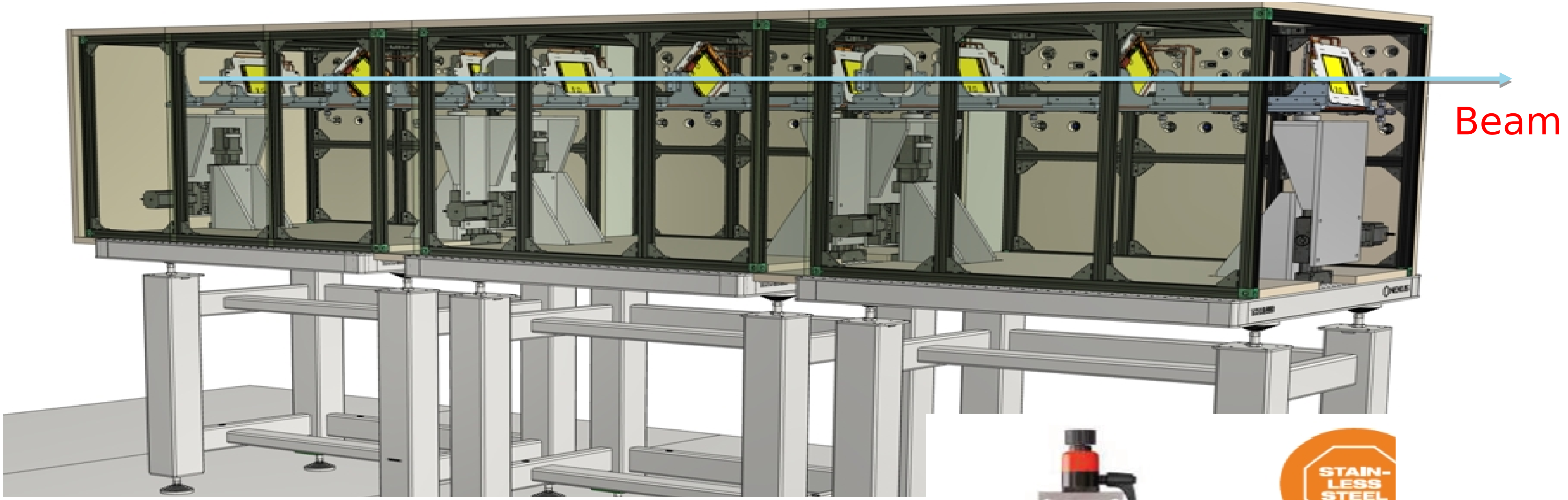
Detection efficiency, background, etc.





The tracking system details

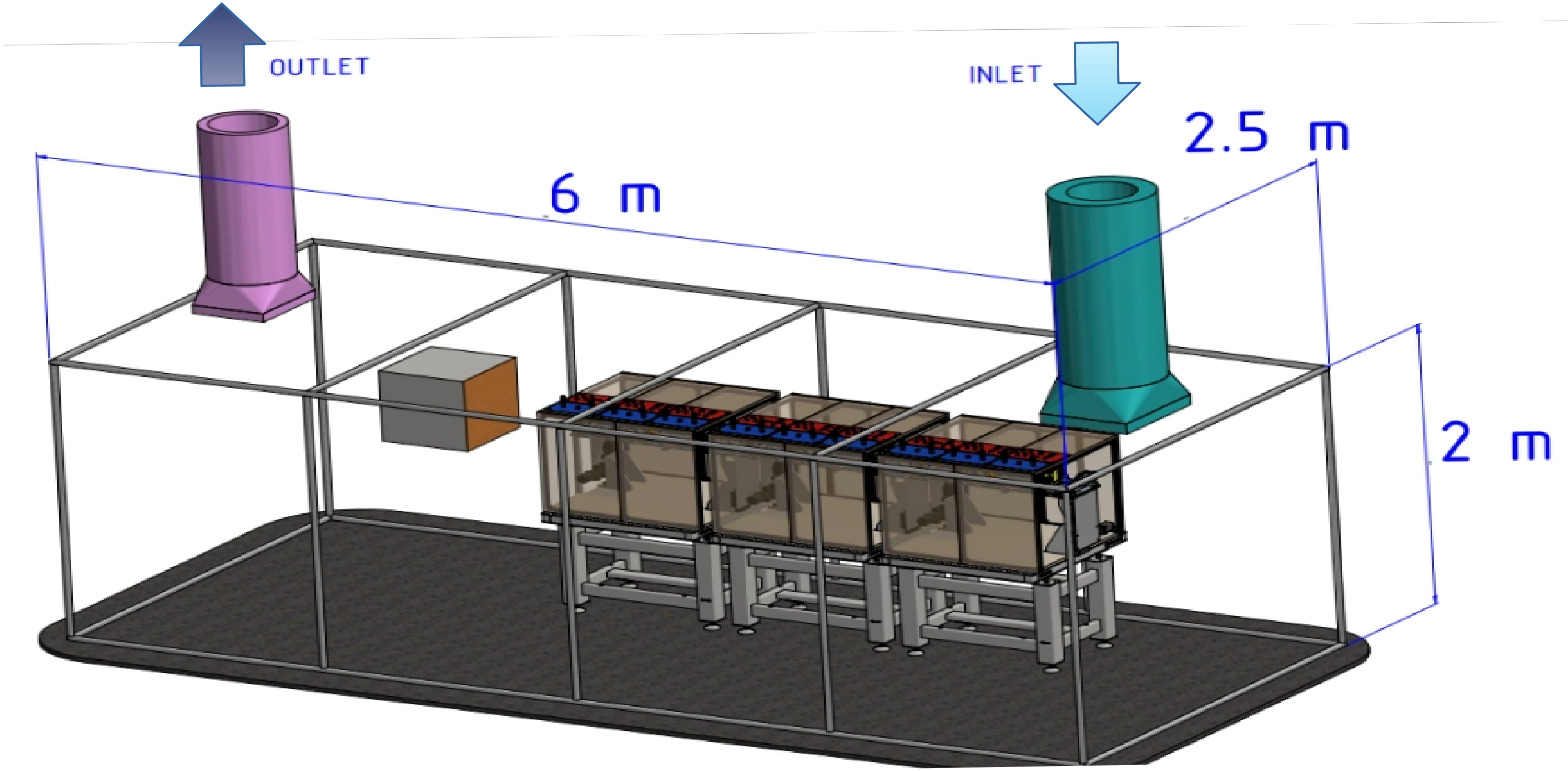
- Each tracker station is mounted on a breadboard through actuators to center the beam and allow for the precise positioning.



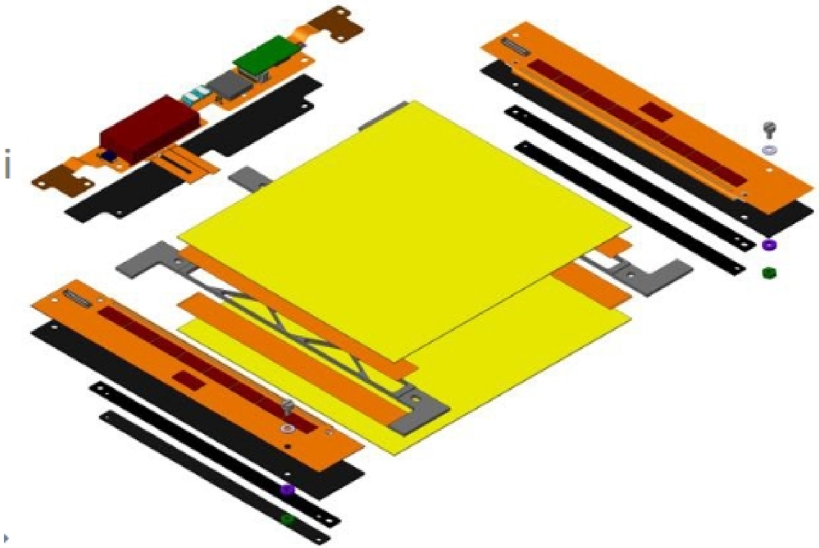
- Three points of support - Linear stages motorized:
  - XY upstream
  - XY and X downstream

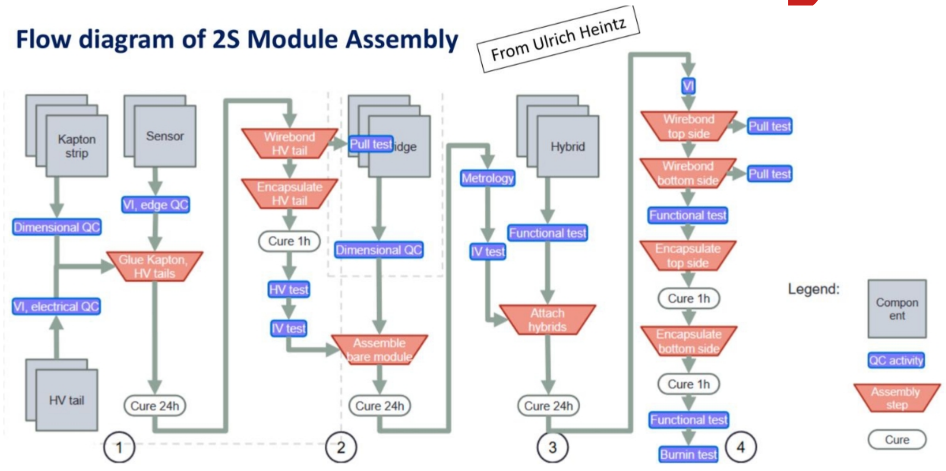
Insulation to get ΔT < ± 1°C

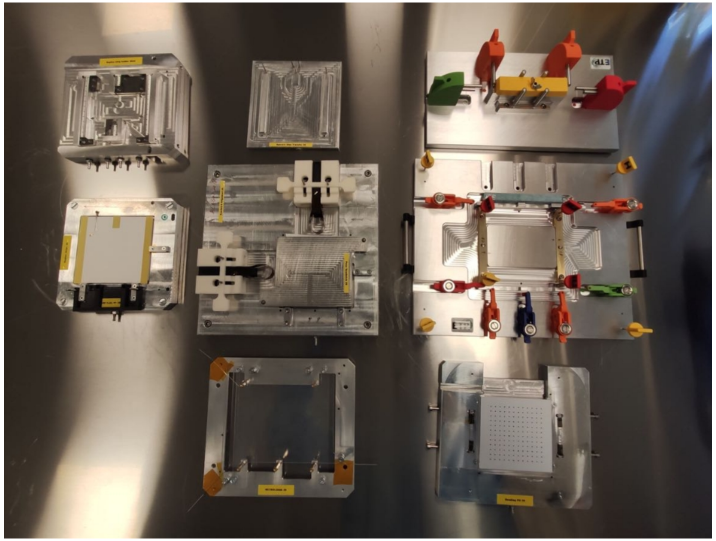
Panels: polyurethane foam (l=0.022 W/mK), 40 mm



2S Modules Assembly





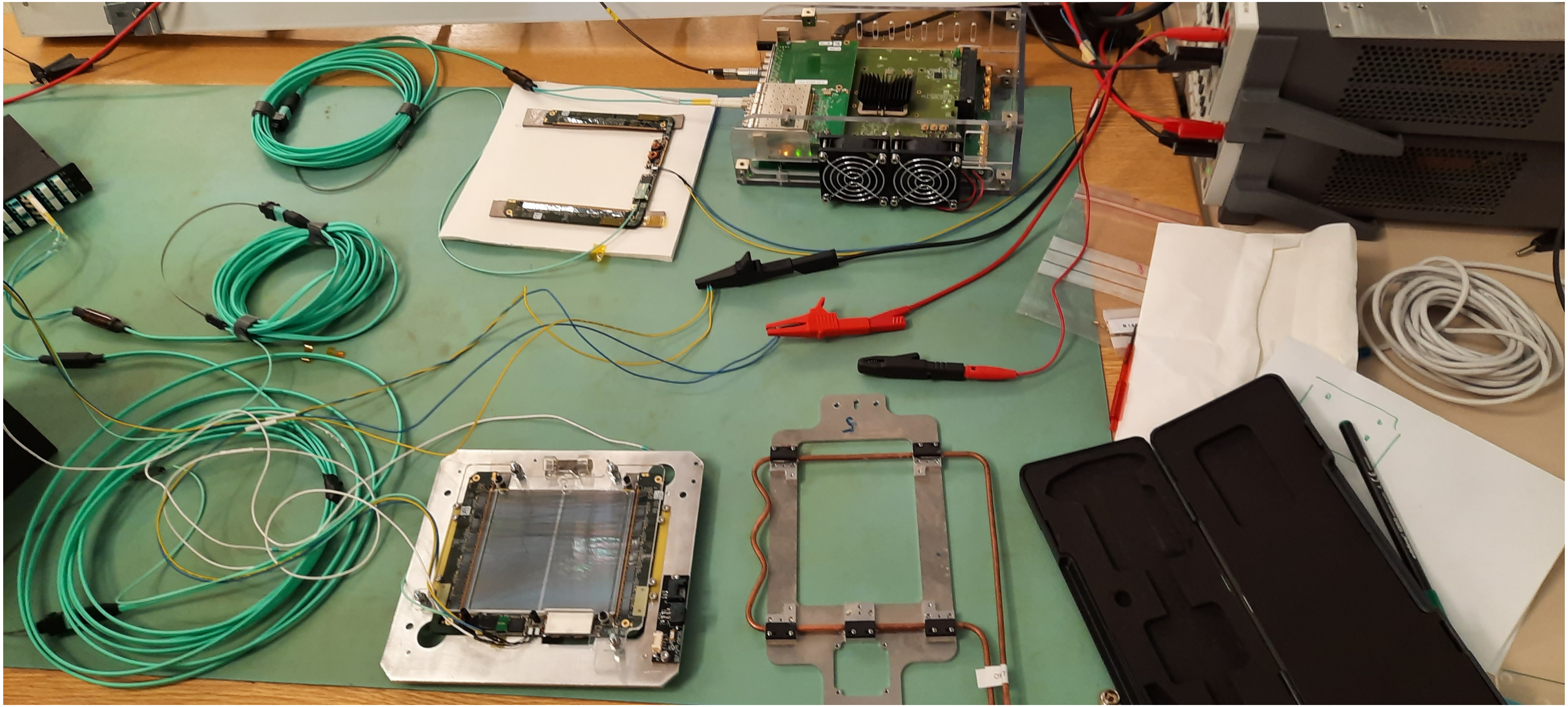


Perugia proved to know how to build the 2S with very good accuracy

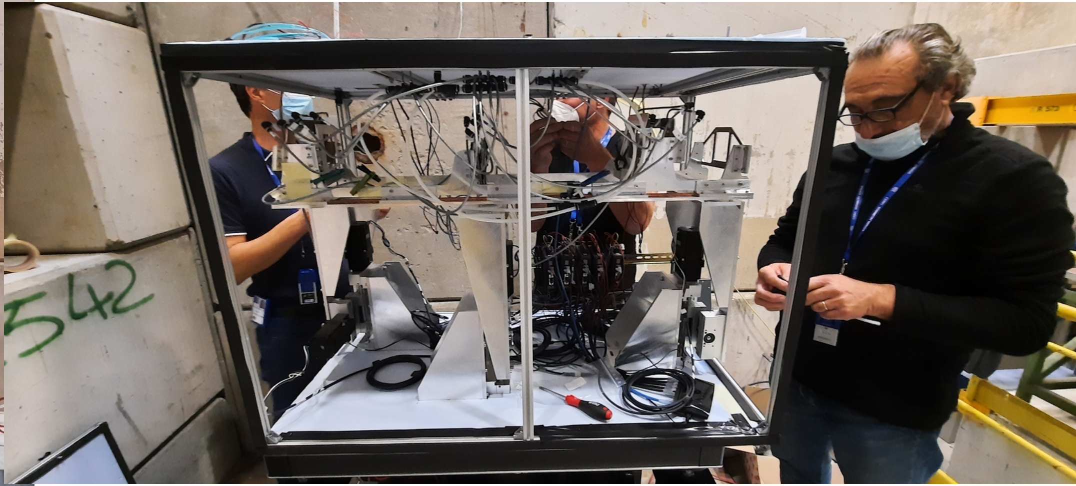
Shortage of 2S modules is the most serious issue we are facing at the moment, because of scarcity of SEH, caused by lpGBT.

First CMS-MUonE tests
of the 2S and DAQ system
November 2021

Laboratory tests

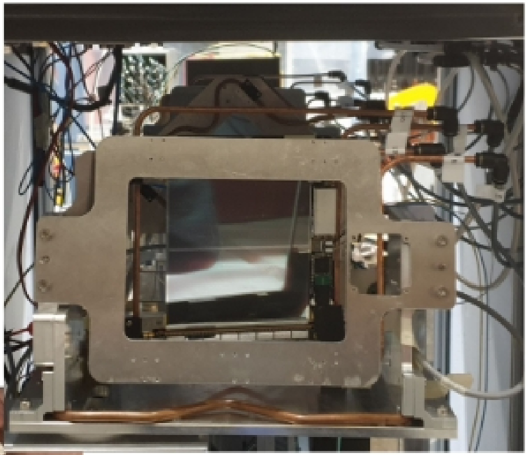


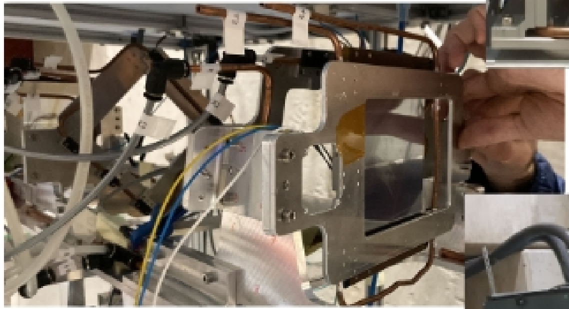
Installing:
downstream the COMPASS detector
Muon beam
40 MHz counting rate capability



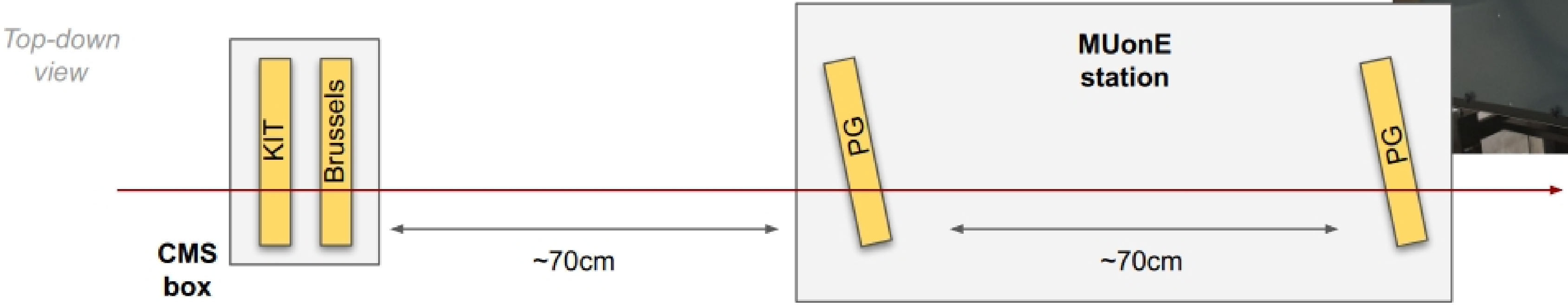
FE Setup

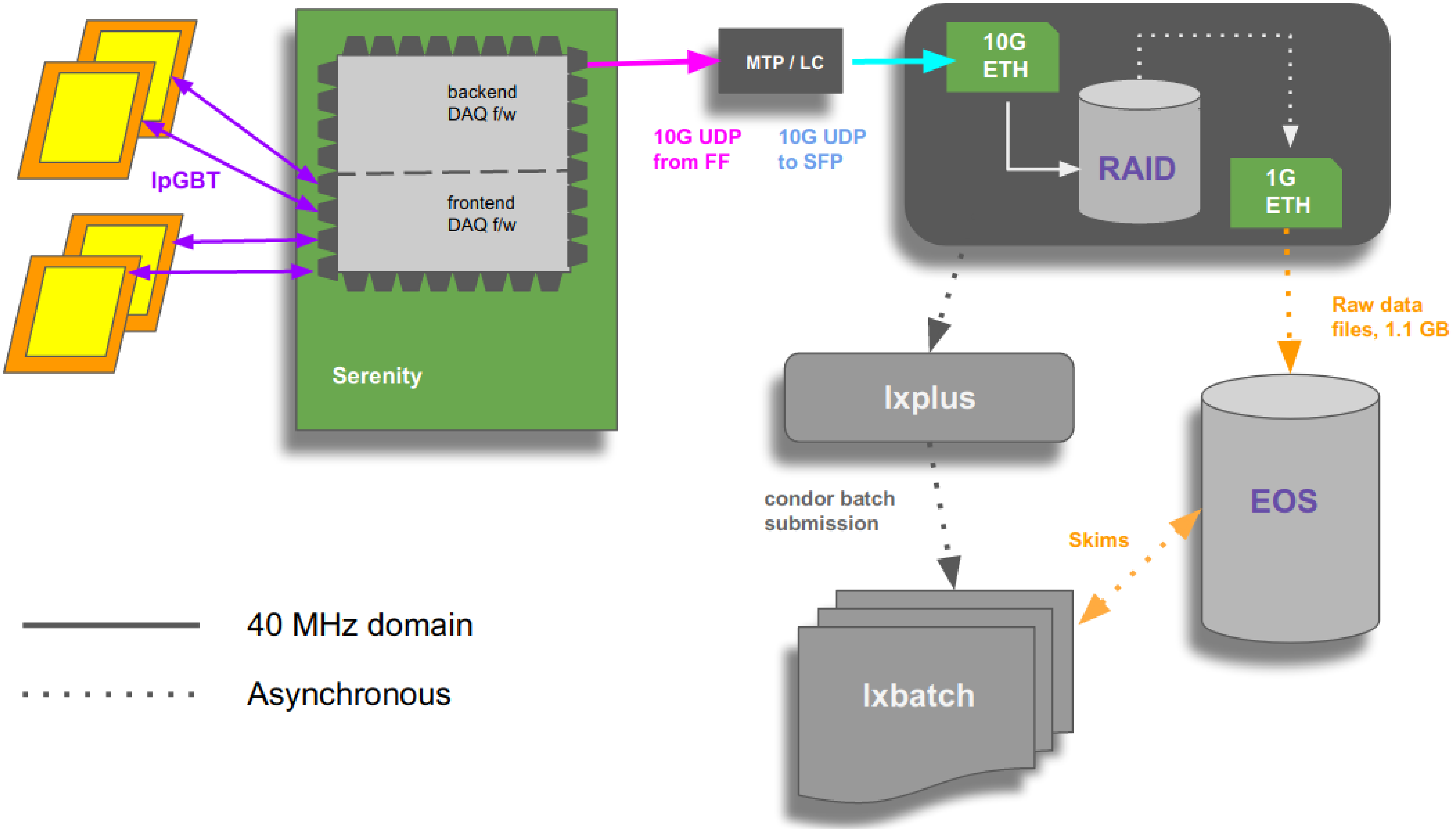
- 2 modules from INFN Perugia installed in MUonE station
  - First 2 modules (1.8mm) produced - one with I2C "patch"
  - Installed in first and last x-coordinate positions, w/o FEH grounding
  - Water cooling (~18C)
  - Using close to final mechanics/connectivity





- 2 modules installed in CMS box
  - KIT #3, & Brussels FM3 (both 1.8mm)
  - Portable, no active cooling
  - On standard CMS frames, w/ FEH grounding




lpGBT
backend
DAQ f/w
frontend
DAQ f/w
Serenity
MTP / LC
10G UDP
from FF
10G UDP
to SFP
10G
ETH
RAID
1G
ETH
Raw data
files, 1.1 GB
lxplus
condor batch
submission
EOS
Skims
lxbatch
40 MHz domain
Asynchronous

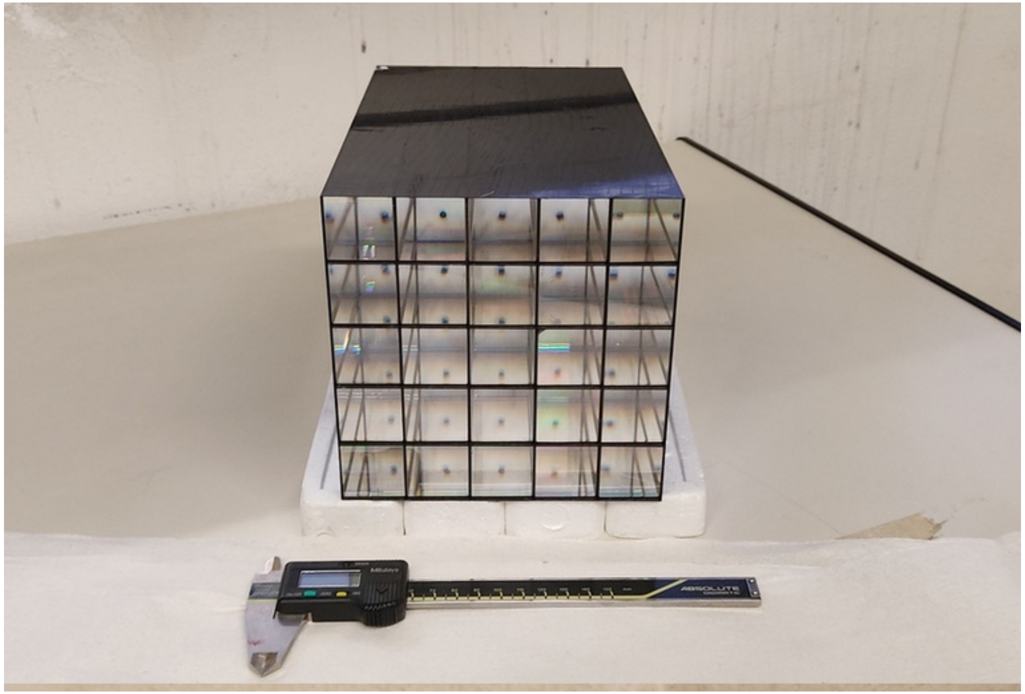
Conclusions

- First opportunity to test MUonE tracking system equipped with station enclosure, environmental control, services and mechanics.
- First 2S modules produced by CMS
- DAQ system based on CMS Phase 2 upgrade
- First demonstration of full chain, with beam, capturing data from 4 modules at full 40MHz rate (triggerless) direct to disk.
- Many hours stable running, despite fact that system is very new: promising !
- Could not complete commissioning of TR apparatus with parasitic beam operations: impacted by NA64 as upstream user we managed to capture ~1 TB of data for offline analysis.
- Will analyse this data to learn about system reliability and commissioning requirements before next TR.
- Will need to complete commissioning of the setup with dedicated beam time in 2022

Backup slides

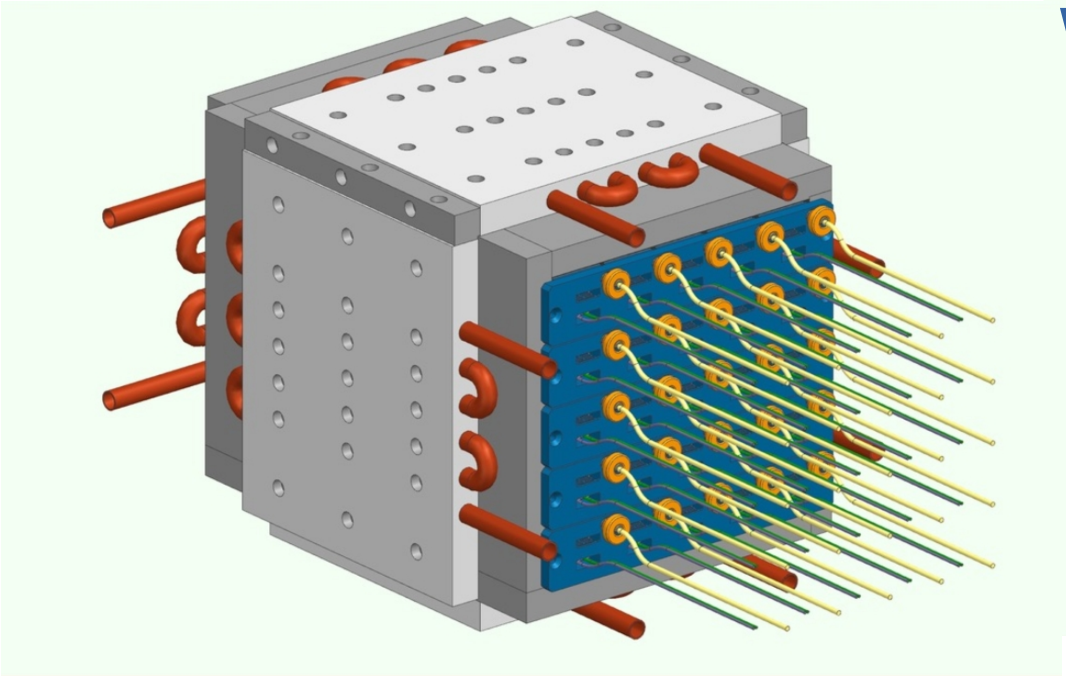
ECAL

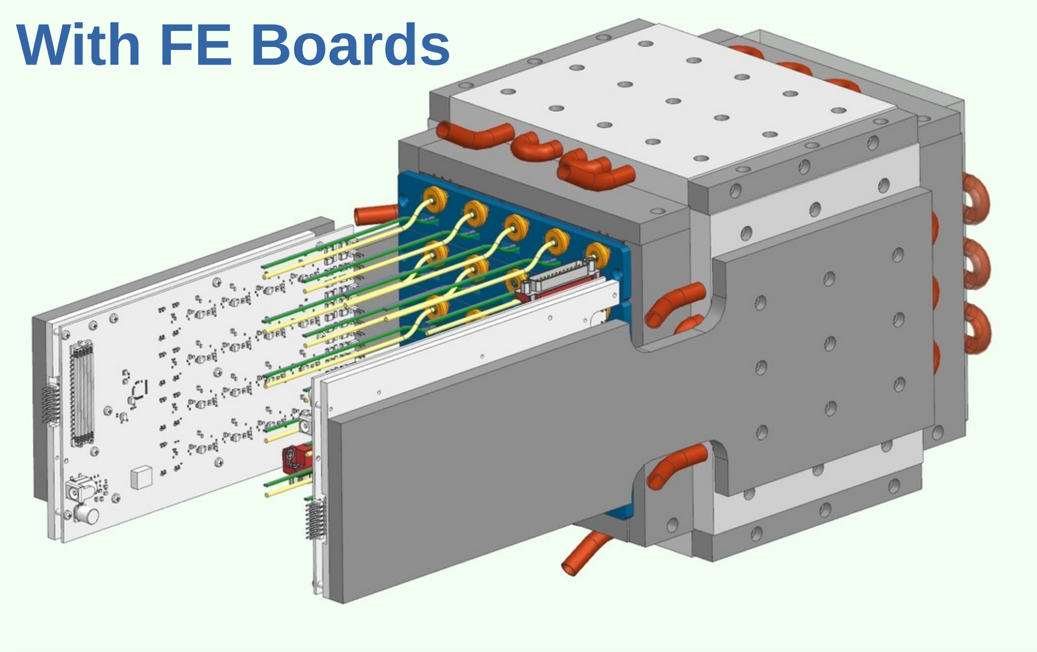
- **Mechanics and crystal tests**
  Padova
- **APDs purchase and test**
  University of Virginia
- **Front End Board**
  Imperial College
- **Laser system**
  Pisa, Trieste
- **HV and LV**
  Krakow



The matrix of 25 PbWO crystals borrowed from CMS

Mechanics layout

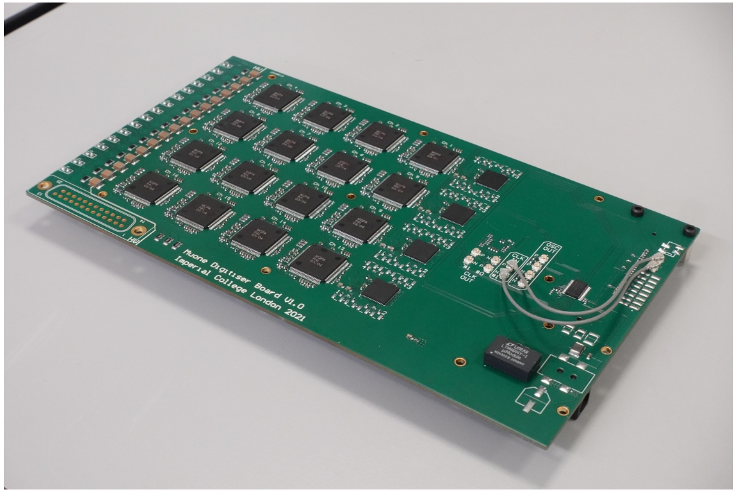


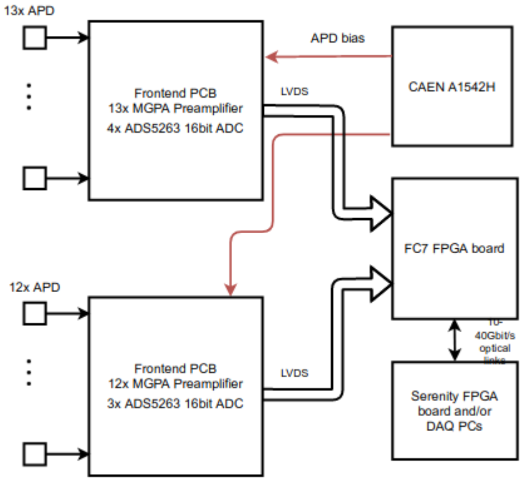


Housing structure for the PbWO crystal matrix. Temperature control through Al plates in contact with the carbon-fiber structure, with pipes for chiller water.

ECAL FEB

- FEB is based on the **MGPA(v2)** preamplifier originally developed for the CMS ECAL (the 16 chips in a 4x4 array). However, in contrast to the CMS ECAL system this board uses only one gain-range for simplicity and reduced power consumption,
- **Commercial 16-bit ADC** (TI ADS5263, the 4 chips in one line). The board contains circuitry for generating the supply voltages for MGPAs and ADCs.
- **Passive networks for biasing the APDs** from an external high-voltage power supply (e.g. the big capacitors along left-hand edge). The small parts between the ADCs and the FMC connector are clock distribution (QFN) and an I2C multiplexer (SO).
- **The data from the ADCs is streamed over the FMC connector** to an **FC7 FPGA** board which collect data streams from 2 frontend boards and in turn stream the data over optical fibers using the **lpGBT protocol to the backend**.





Fast ECAL simulation

5 input parameters

SHOWER PARAMETRIZATION

"GFLASH" By Grindhammer and Peters [arXiv:hep-ex/0001020]

ENERGY DISTRIBUTION: $dE(\vec{r}) = E f(t)dt\, f(r)dr\, f(\phi)d\phi$

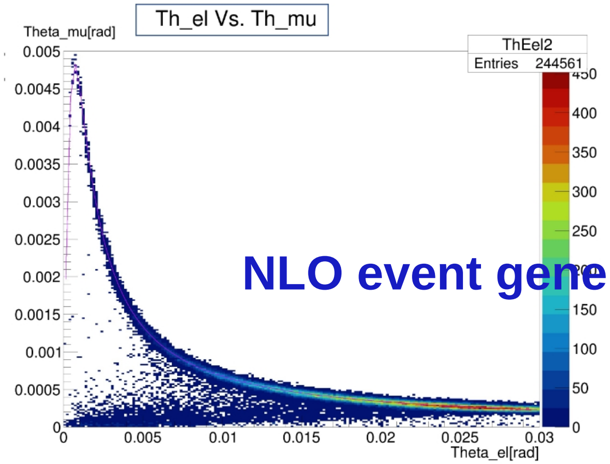
- Longitudinal profile as a function of t (shower depth in unit of X_0)
- Radial profile as a function of r (transversal distance in units of R_M)
- Function of azimuthal angle assumed uniform

AVERAGE:

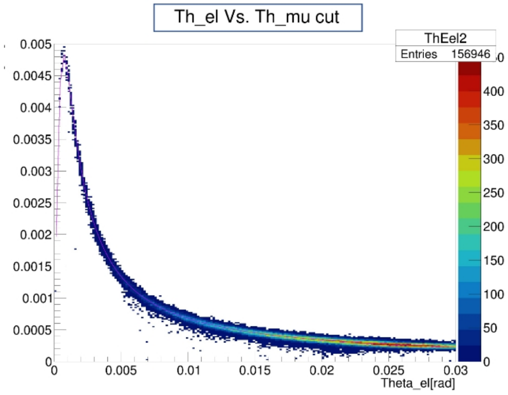
$$f(t) = \frac{(\beta t)^{\alpha-1}\beta\exp(-\beta t)}{\Gamma(\alpha)}$$

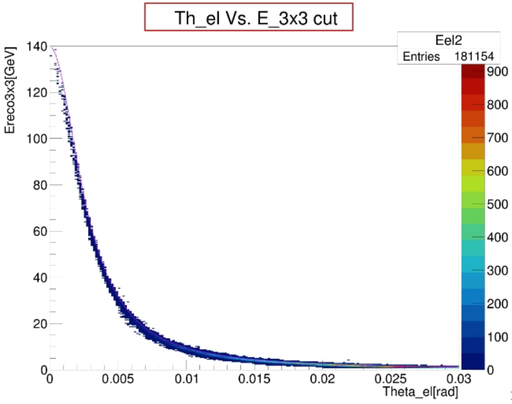
$$f(r) = p\frac{2rR_C^2}{(r^2+R_C^2)^2} + (1-p)\frac{2rR_T^2}{(r^2+R_T^2)^2}$$

https://amslaurea.unibo.it/23207/



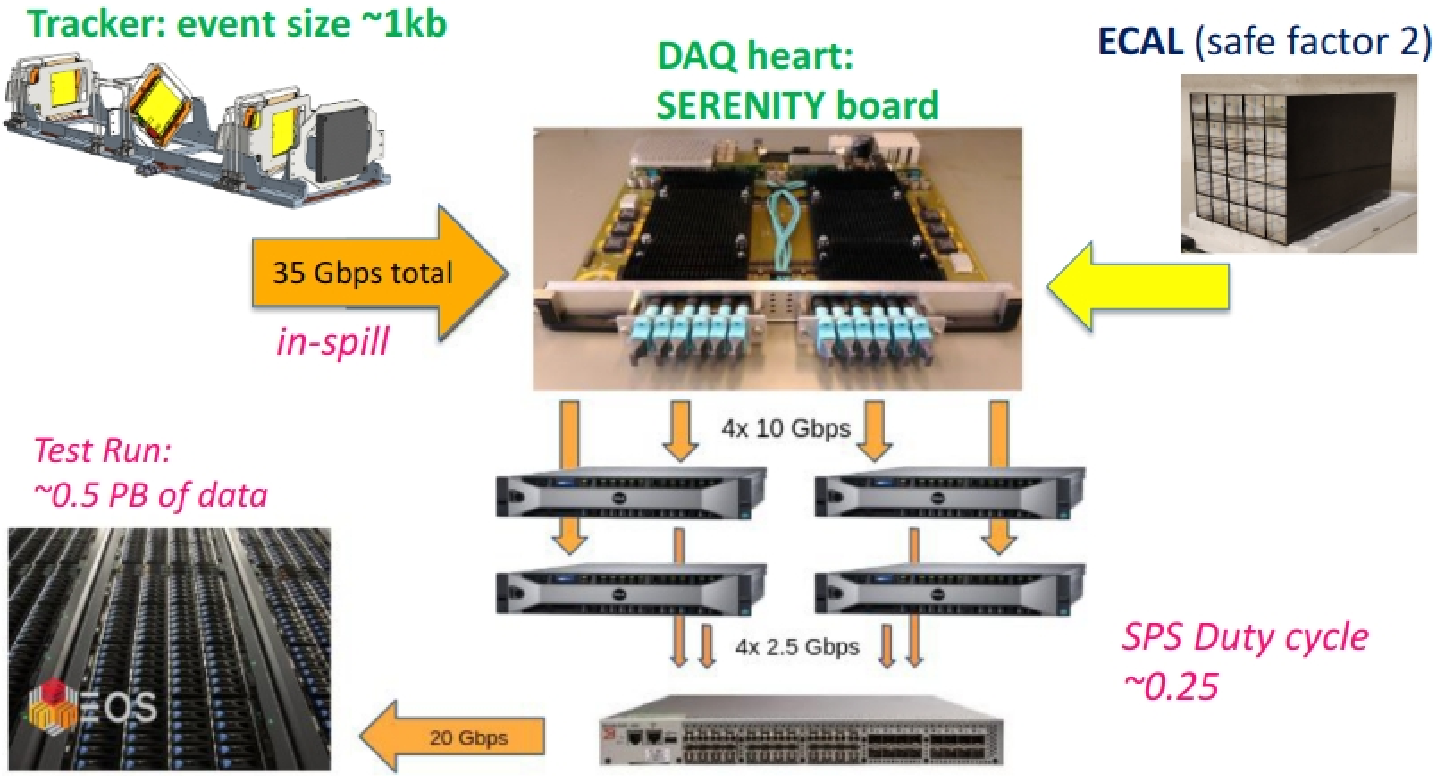
NLO event generator





Applying elasticity selection cuts

DAQ



Tracker: event size ~1kb
DAQ heart:
SERENITY board
ECAL (safe factor 2)
35 Gbps total
in-spill
4x 10 Gbps
Test Run:
~0.5 PB of data
EOS
4x 2.5 Gbps
SPS Duty cycle
~0.25
20 Gbps