Status of the MUonE experiment

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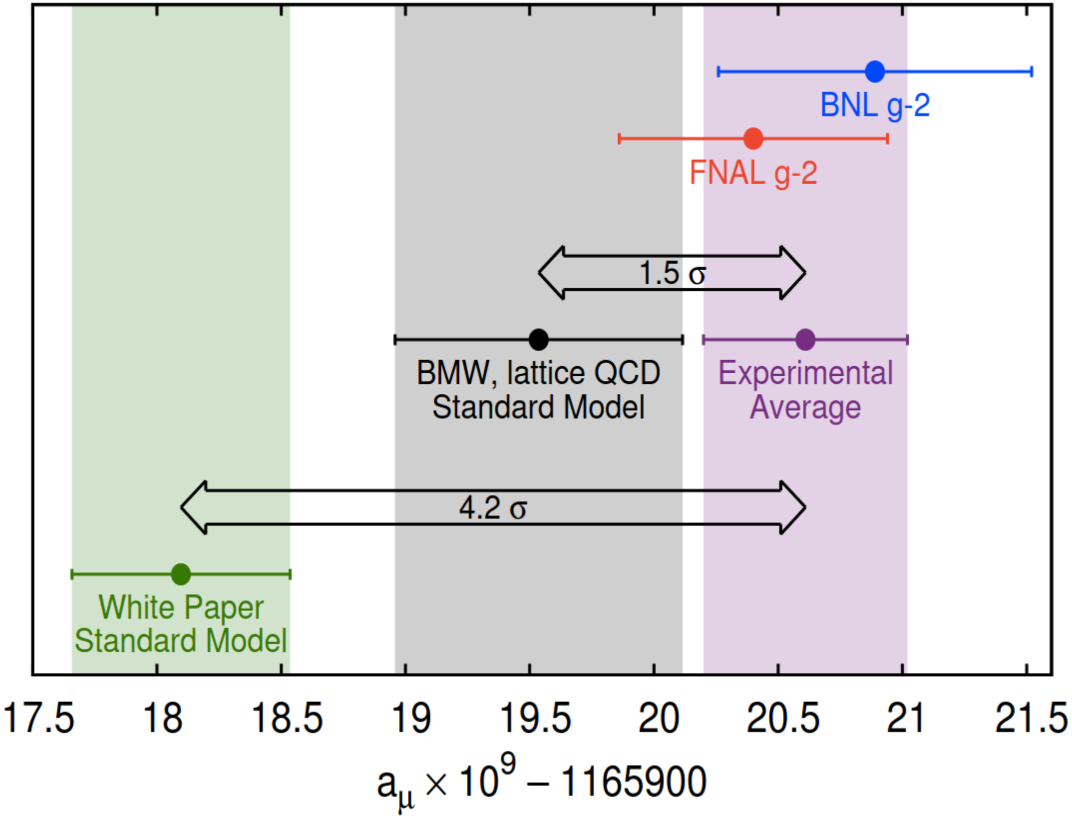
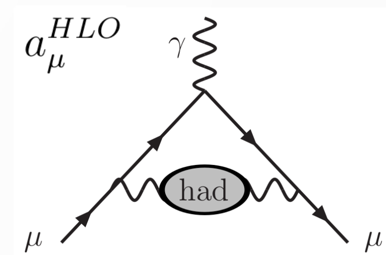
The muon g-2: latest results



Discrepancy between BMW and time-like (WP20) results.

Main contribution to the Standard Model uncertainty:

hadronic contribution a_μ^{HLO}



- Traditional time-like approach: relies on experimental data $e^+e^- \rightarrow hadrons$.

Precision currently achieved on a_μ^{HLO}:

0.6% (WP20)

Aoyama et al, Phys. Rep. 887 (2020), 1

- Lattice QCD: BMW collaboration recently achieved a 0.8% precision.

Borsanyi et al, Nature 593, 51–55 (2021)

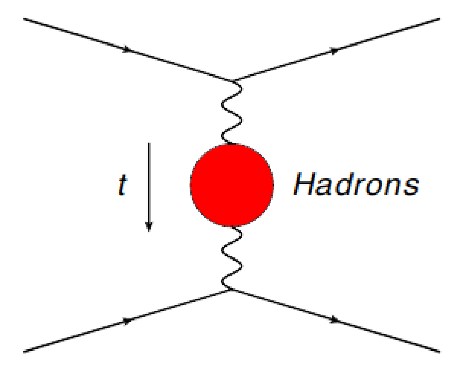
a_μ^{HLO} : space-like approach

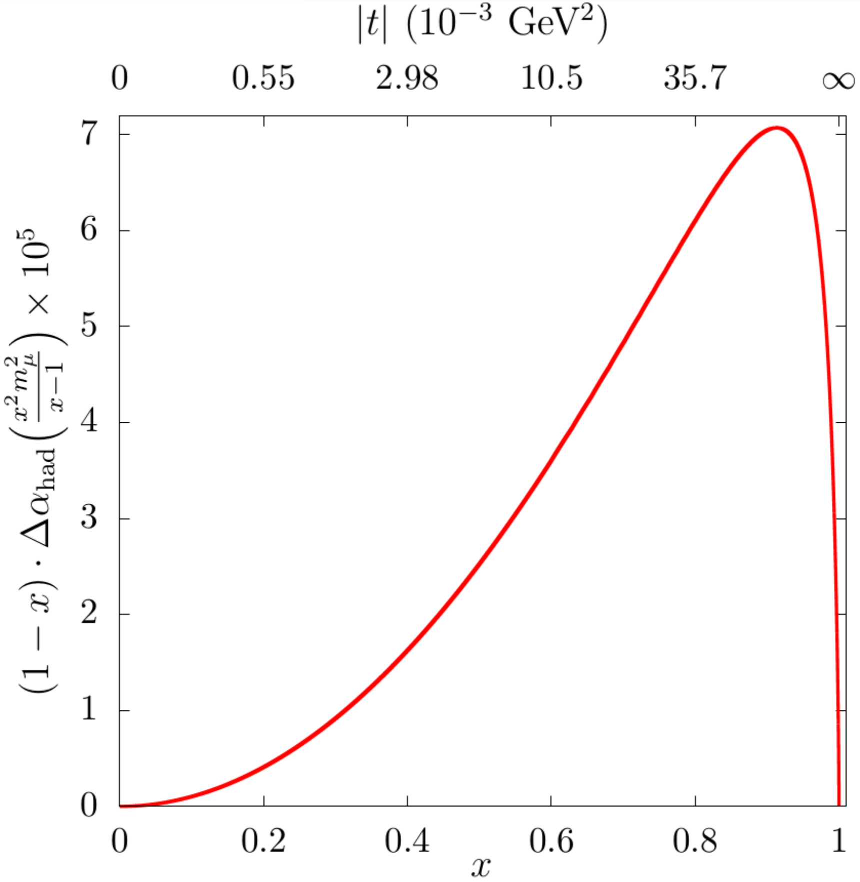
MUonE: a new independent evaluation of a_μ^{HLO}

$$a_\mu^{HLO} = \frac{\alpha_0}{\pi} \int_0^1 dx(1-x)\Delta\alpha_{had}[t(x)]$$

Lautrup, Peterman, De Rafael, Phys. Rep. C3 (1972), 193

$$t(x) = \frac{x^2 m_\mu^2}{x-1} < 0$$





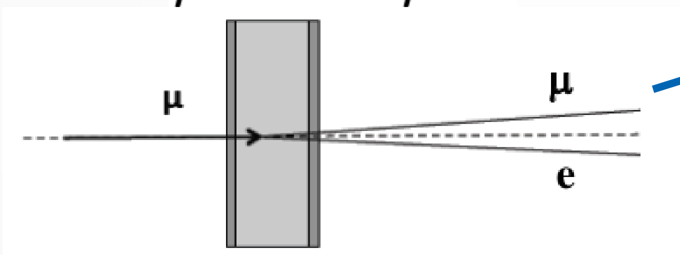
Carloni Calame, Passera, Trentadue, Venanzoni, Phys. Lett. B 746 (2015), 325

Based on the measurement of $\Delta\alpha_{had}(t)$: hadronic contribution to the running of the electromagnetic coupling constant.

The MUonE experiment

Extraction of $\Delta\alpha_{had}(t)$ from the differential cross section of the interaction

$$\mu\ e \rightarrow \mu\ e$$

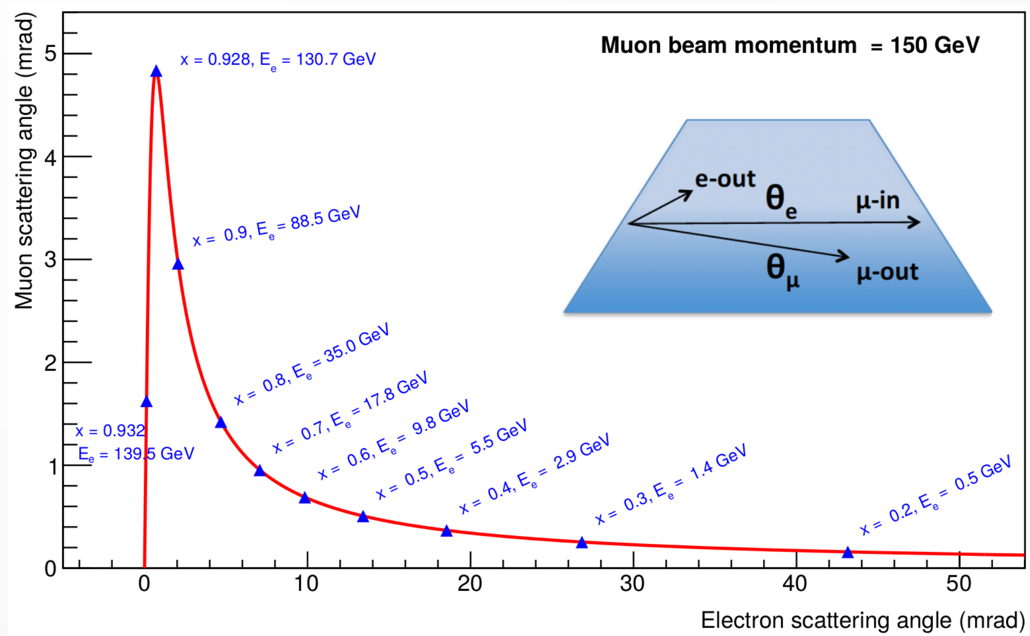


$$\frac{d\sigma_{data}/dt}{d\sigma_{MC}^{\text{no VP}}/dt} = \frac{1}{|1 - \Delta\alpha_{lep}(t) - \Delta\alpha_{had}(t)|^2}$$

From theoretical calculation

To be measured

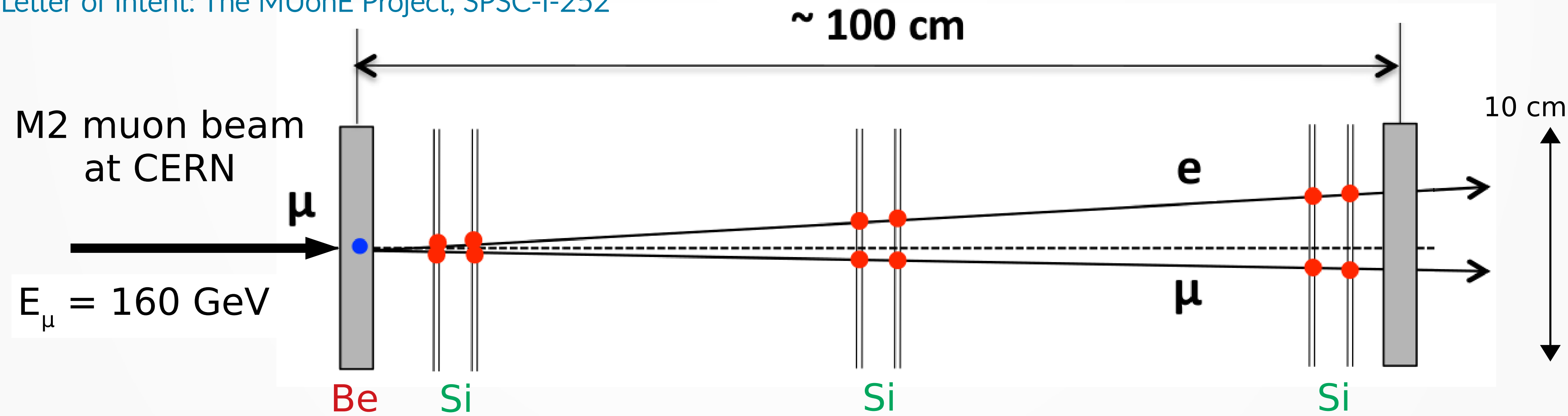
- A beam of 160 GeV muons allows to cover 87% of the a_μ^{HLO} integral.
- Correlation between muon and electron angles allows to select elastic events and reject background (e^+e^- pair production).
- Boosted kinematics: $\theta_\mu < 5$ mrad, $\theta_e < 32$ mrad.



Abbiendi et al, Eur. Phys. J. C 77.3 (2017), 139

The experimental apparatus

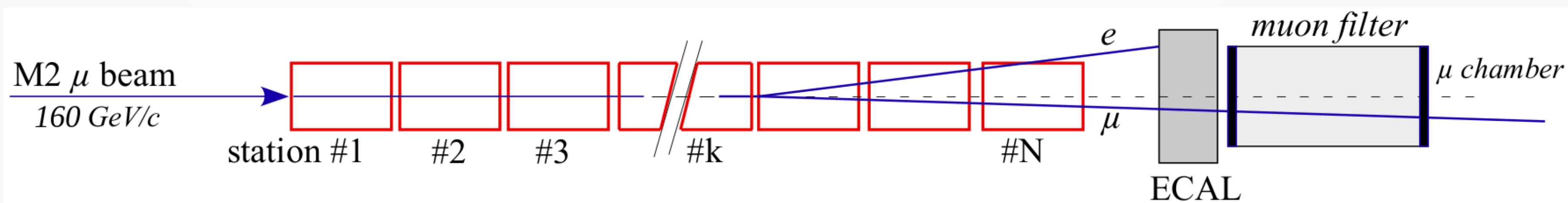
Letter of Intent: The MUonE Project, SPSC-I-252



Beryllium target
1.5 cm thickness

Tracking system: 3 pairs of
silicon strip detectors

× 40



Achievable accuracy

40 stations + 3 years of data taking ($I_\mu \sim 10^7$ μ^+/s) = ~0.3% statistical accuracy on a_μ^{HLO}

Competitive with the latest time-like accuracy.

The big challenge of the experiment is to reach a comparable systematic accuracy

Systematic uncertainty of 10 ppm at the peak of the integrand function

- Longitudinal alignment (~10 μm)
- Knowledge of the beam energy (few MeV)
- Multiple scattering (~1%)

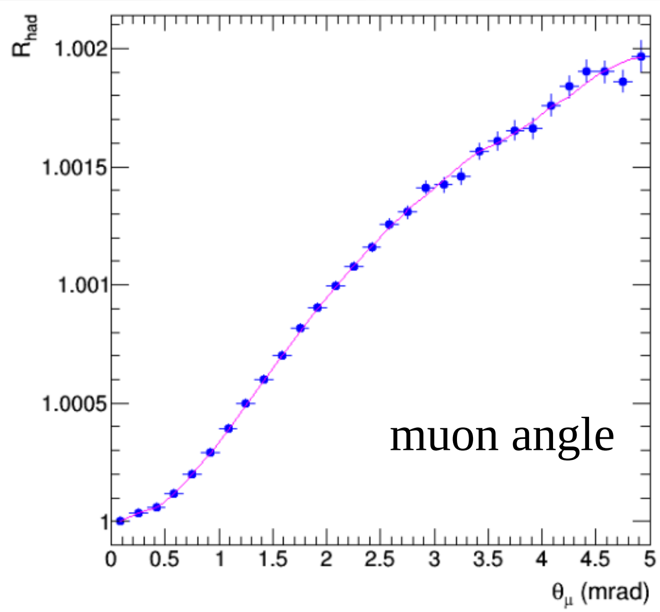
Extraction of a_μ^{HLO}

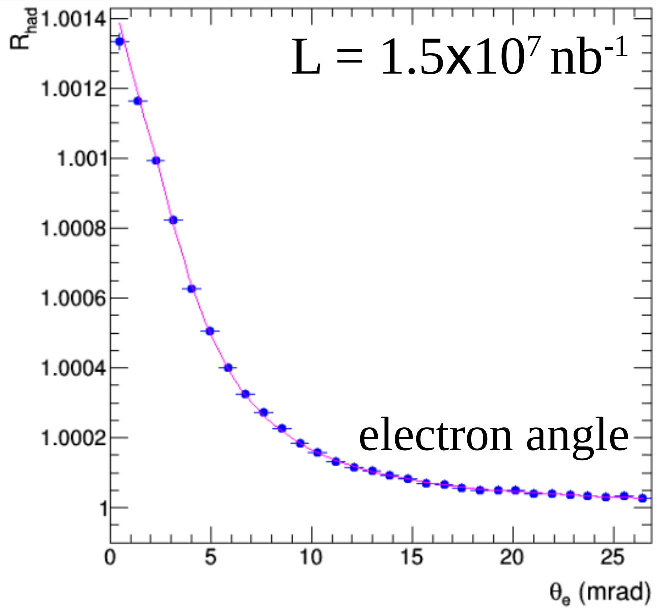
$\Delta\alpha_{had}(t)$ parameterization: inspired from the 1 loop QED contribution of lepton pairs and top quark at t<0

$$\Delta\alpha_{had}(t) = KM\left\{-\frac{5}{9} - \frac{4}{3}\frac{M}{t} + \left(\frac{4}{3}\frac{M^2}{t^2} + \frac{M}{3t} - \frac{1}{6}\right)\frac{2}{\sqrt{1-\frac{4M}{t}}}\ln\left|\frac{1-\sqrt{1-\frac{4M}{t}}}{1+\sqrt{1-\frac{4M}{t}}}\right|\right\}$$

K, M are the fit parameters.

Extraction of $\Delta\alpha_{had}(t)$ through a template fit to the 2D (θ_e, θ_μ) distribution:





$$R_{had} = \frac{d\sigma(\Delta\alpha_{had})}{d\sigma(\Delta\alpha_{had} = 0)}$$

Results of a toy experiment with full statistics:

$a_\mu^{HLO} = (688.8 \pm 2.4)\ 10^{-10}$

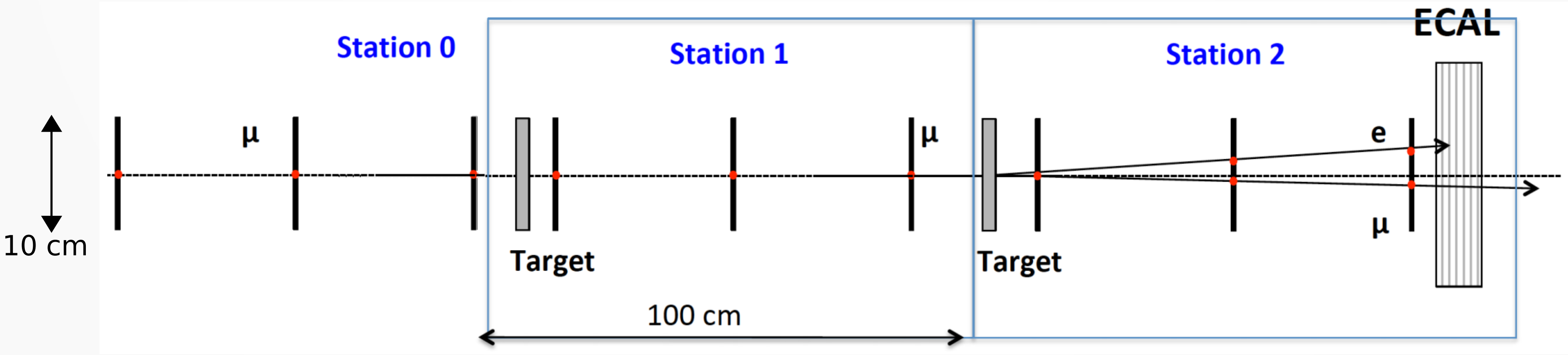
Input value:

$a_\mu^{HLO} = 688.6\ 10^{-10}$

Test Run 2021-2022

A Test Run with a reduced detector has been approved by SPSC, to validate our proposal. It is foreseen in early 2022.

A parasitic Run with few Silicon detectors will be held in Fall 2021 to test the DAQ system.



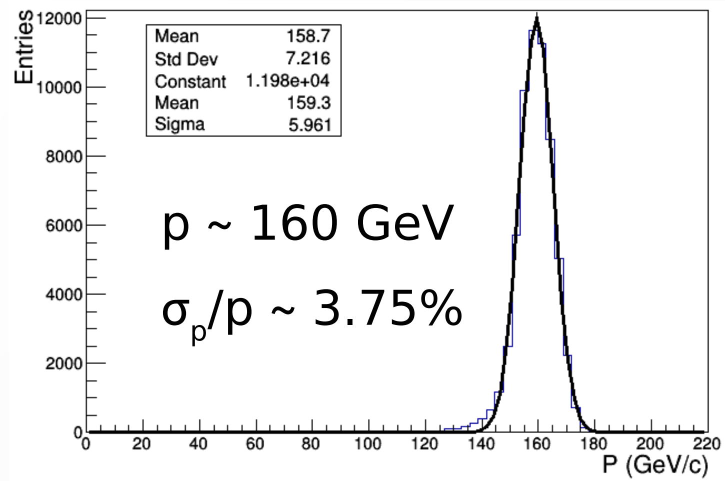
- Pretracker +
- 2 MUonE stations +
- ECAL

Main goals:

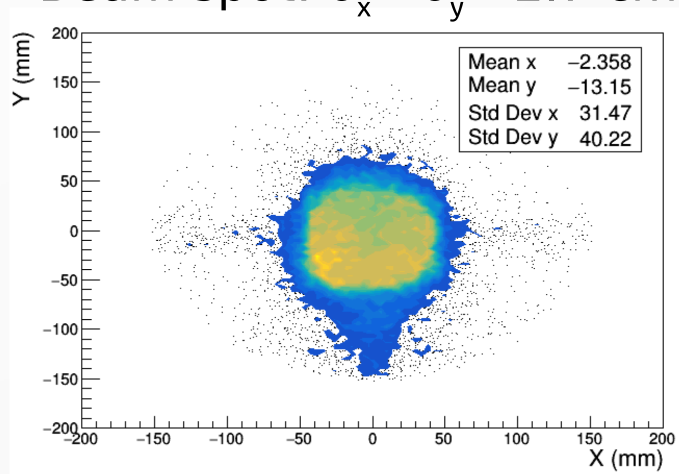
- Confirm the system engineering.
- Monitor mechanical and thermal stability.
- Assess the systematic errors.
- Take data to extract $\Delta\alpha_{\mathrm{lep}}(t)$.

Location: M2 beam line at CERN

Beam momentum



Beam spot: $\sigma_x \sim \sigma_y \sim 2.7$ cm



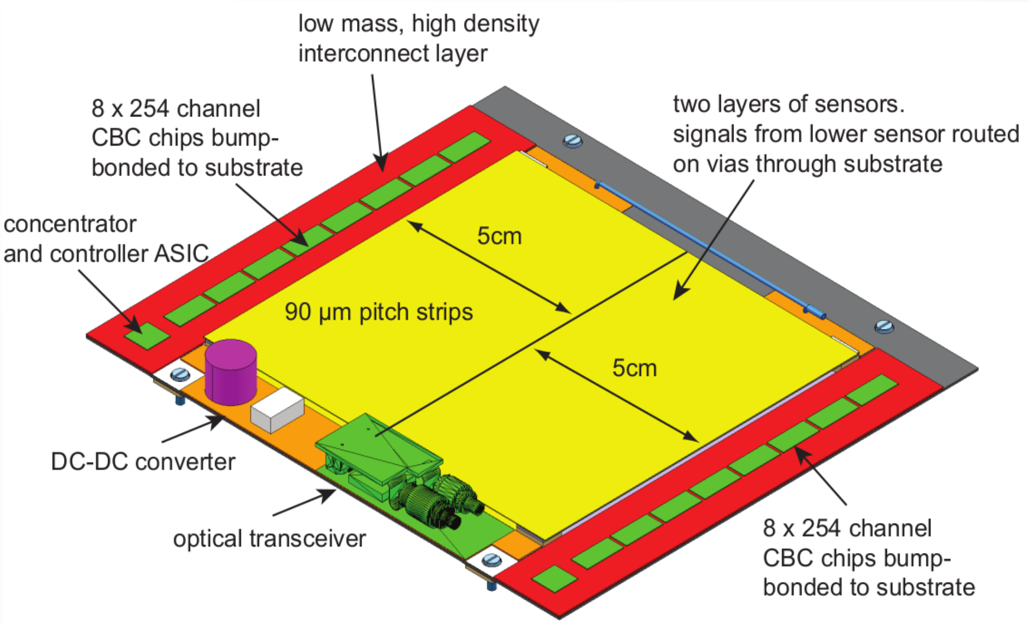
- Location: upstream the COMPASS detector (CERN North Area).
- Low divergence muon beam: $\sigma_{x'} \sim \sigma_{y'} \sim 0.3$ mrad.
- Spill duration ~ 5 s. Duty cycle ~ 25%.
- Maximum rate: 50 MHz (~ 3×10^{8} μ^{+}/spill).

Tracker: CMS 2S modules

Silicon strip sensors currently in production for the CMS-Phase2 upgrade.

Two close-by strip sensors reading the same coordinate.

This provides background suppression from single-sensor hits and rejection of large angle tracks.



- Thickness: $2 \times 320\ \mu\text{m}$
- Pitch: $90\ \mu\text{m} \rightarrow \sigma_x \sim 26\ \mu\text{m}$
- Readout rate: $40\ \text{MHz}$
- Area: $10\ \text{cm} \times 10\ \text{cm}$ → Complete and uniform angular acceptance with one module.

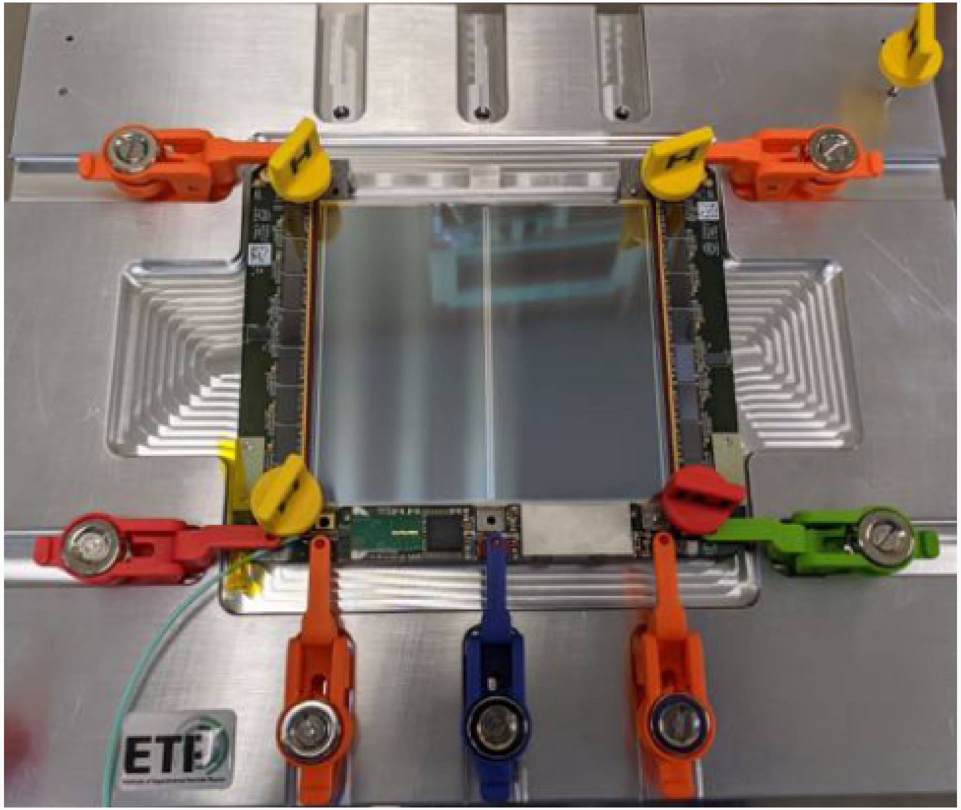
Tracker: CMS 2S modules

- Two dummy modules were built in the assembly center of Perugia to assess the procedure.
- First functional module has been assembled in the last few weeks.

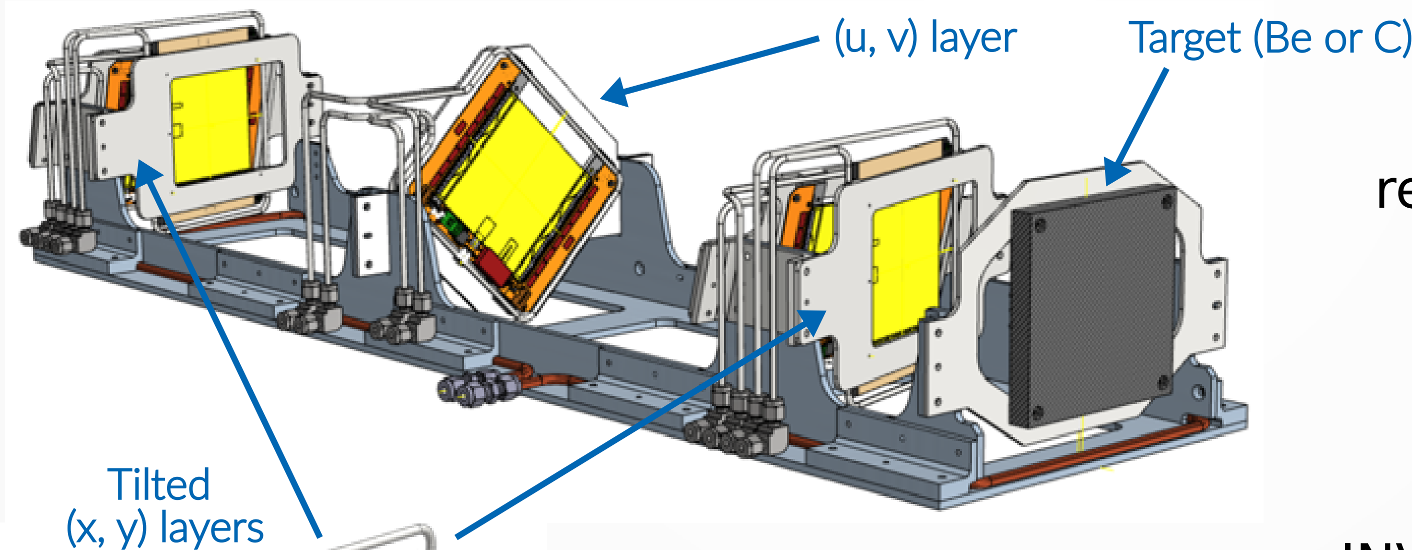
The module will be sent to CERN for the development of the DAQ system.

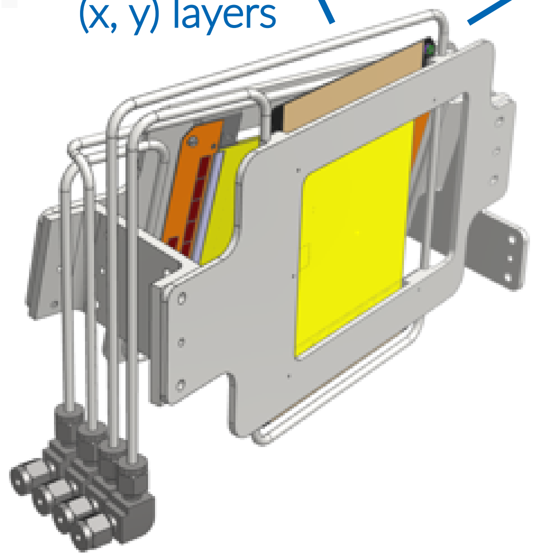
Its performances will be tested during the Parasitic Run.

We are ready to build more 2S modules, as soon as components will be available.



Tracking station





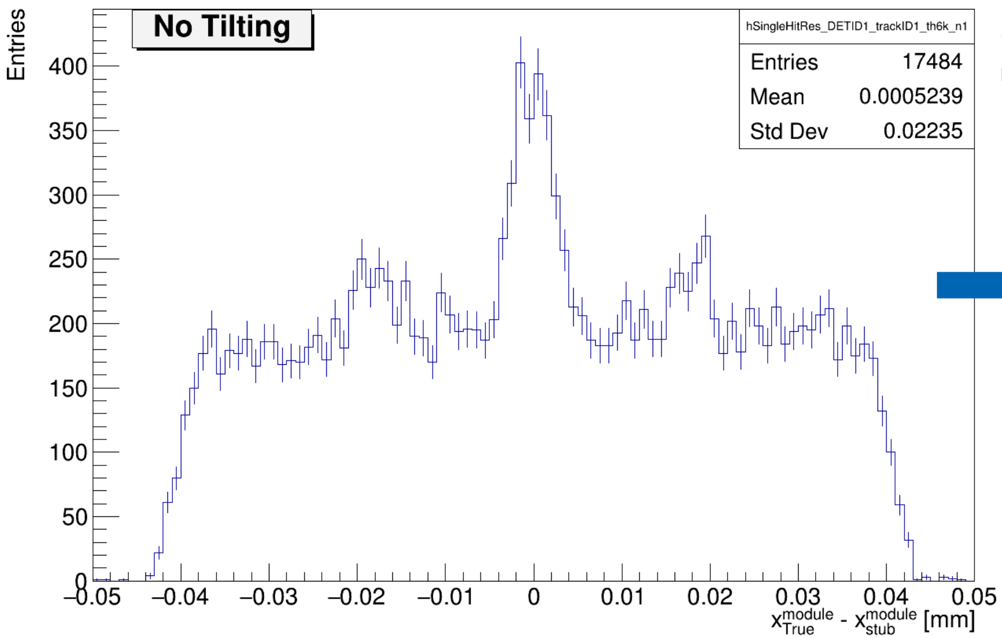
Stringent request:
relative position within
a station must be
stable at 10 μm.

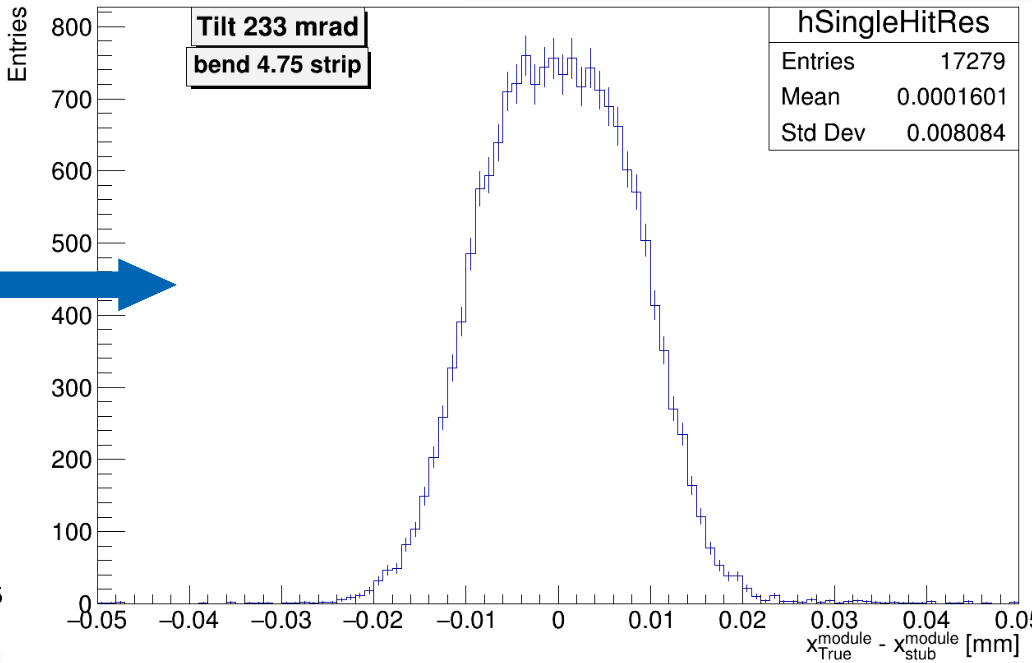
↓

Low CTE material:
INVAR (CTE ~ 1.2×10^{-6} K^{-1})

- (x, y) layers tilted by 233 mrad, to improve single hit resolution.
    - Simulation studies show a resolution of ~10 μm.
- (u, v) layers to solve reconstruction ambiguities.

Simulation: Improving resolution - tilted geometry





Improvement due to:

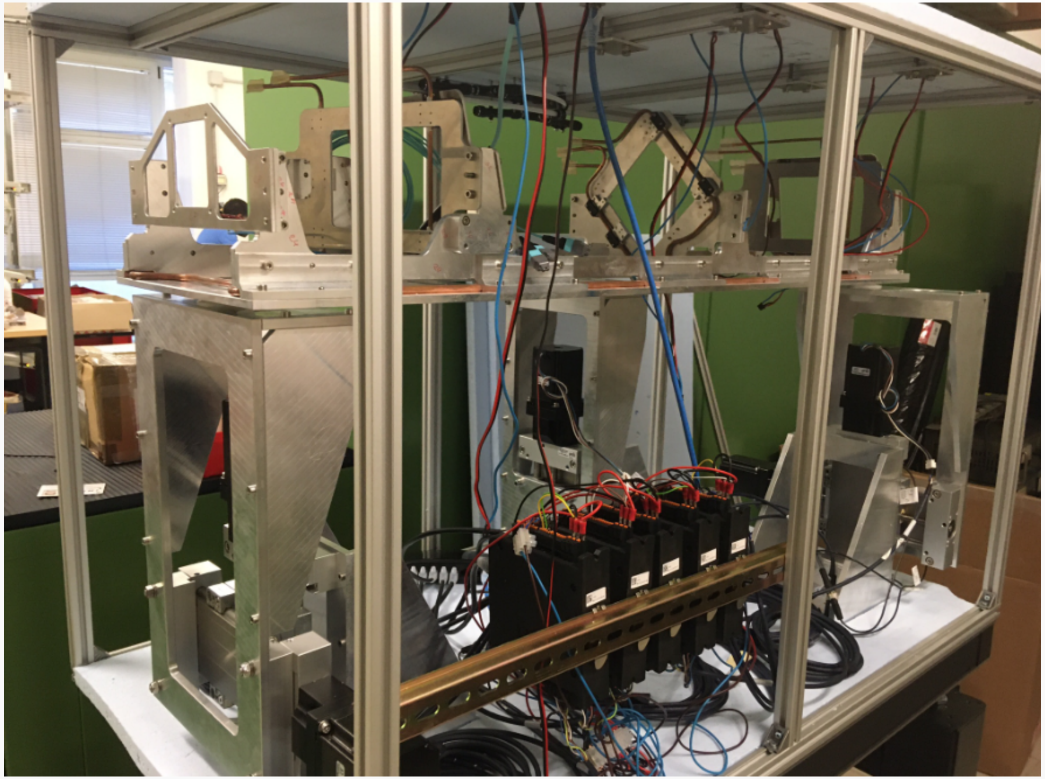
- charge sharing between adjacent strips
- effective staggering: tilting a 2S module by 25 mrad is equivalent to stagger the two sensors by ½pitch

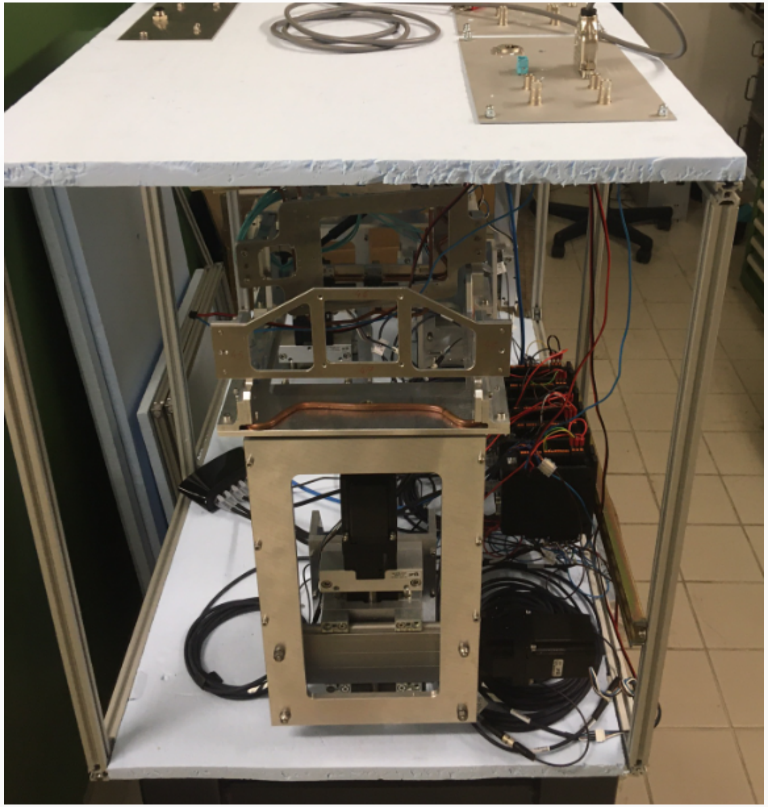
Final resolution

22 μm → 8-11 μm

Tracking station

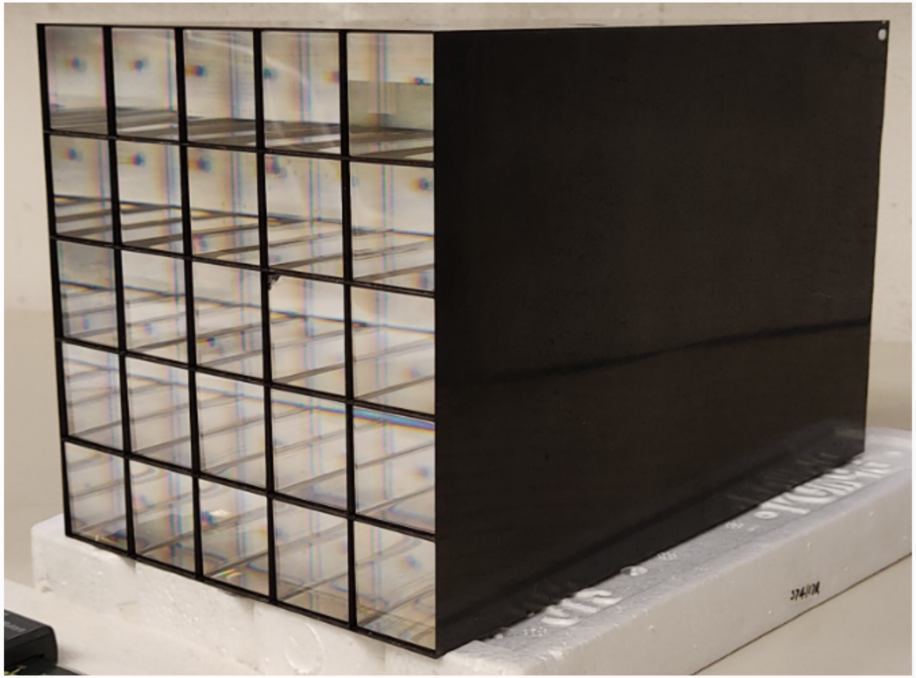
- Aluminum mockup is ready.
- Stepper motors will be used to align the station to the beam.
- Cooling system under test.





ECAL

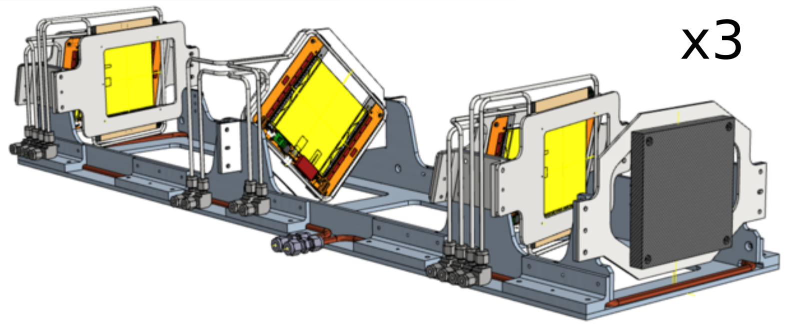
- 5x5 $PbWO_4$ crystals (CMS ECAL).
    - 2.85x2.85 cm^2.
    - Length: 22cm (~25 X_0).
- Total area: ~14x14 cm^2.
- Readout: APD sensors, 10x10mm^2 photosensitive area.



Mechanics and crystal tests currently ongoing in Padova.

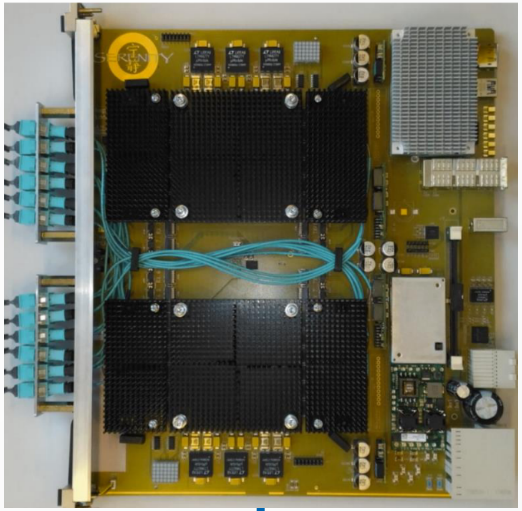
Test on APDs performed by University of Virginia.

DAQ system



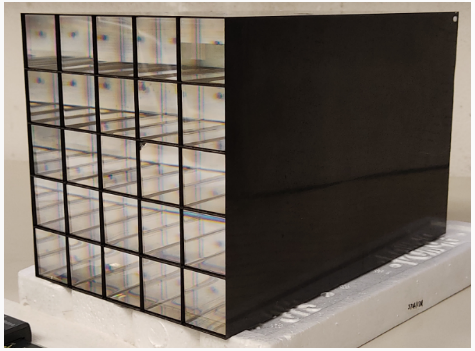
x3

CMS Serenity board



~ 35Gbps in spill

ECAL

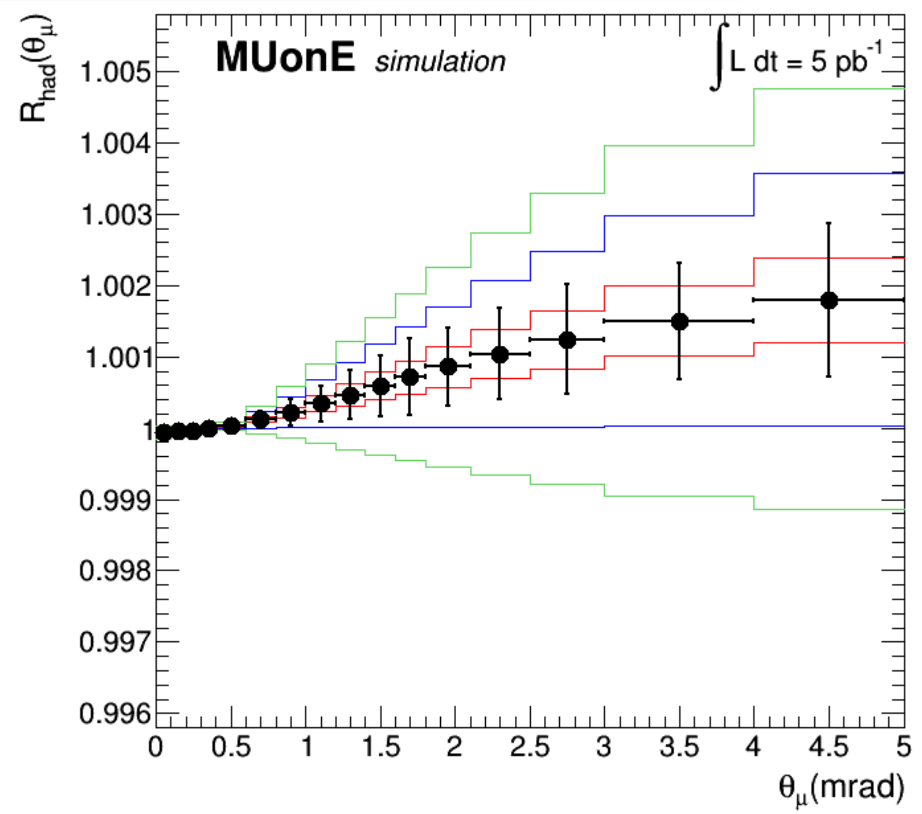


STORAGE

- Parasitic Run will provide a first proof of concept of the DAQ chain.
- Test Run: read all data with no event selection.
- Information will be used to determine online selection algorithms to be used in the Full Run.

Sensitivity to $\Delta\alpha_{had}(t)$

Expected luminosity for the Test Run: L = 5 pb^{-1} ⟷ ~10^9 events with $E_e > 1$ GeV ($\theta_e < 30$ mrad)



$$R_{had} = \frac{d\sigma(\Delta\alpha_{had})}{d\sigma(\Delta\alpha_{had} = 0)}$$

$t_{max} \sim -0.150$ GeV^2

Initial sensitivity to the hadronic running ($\Delta\alpha_{had}(t_{max}) \sim 10^{-3}$):

1D θ_μ fit: K = 0.137 ± 0.027 (pure statistical level)

Definitevely, we will be sensitive to the leptonic running ($\Delta\alpha_{lep}(t_{max}) \sim 10^{-2}$)

Results of a template fit with just K as a fit parameter.
The other parameter if fixed at its expected value: M = 0.0525 GeV^2

Theory

- NLO exact calculation with full mass dependence and EW corrections. A MC generator is currently under use.
- Two independent MC with approximate NNLO: MESMER (Pavia), MCMULE (PSI).
- Huge theoretical activity ("Theory for muon-electron elastic scattering @ 10ppm", P.Banerjee et al, Eur. Phys. J. C80 (2020) 591):
  - P. Mastrolia, M. Passera, A. Primo, U. Schubert, JHEP 1711 (2017) 198
  - S. Di Vita, S. Laporta, P. Mastrolia, A. Primo, U. Schubert, JHEP 1809 (2018) 016
  - M. Alacevich et al, JHEP 02, 155 (2019)
  - M. Fael, JHEP 1902 (2019) 027
  - M. Fael, M. Passera, PRL 122 (2019) 192001
  - C.M. Carloni Calame et al, JHEP 11, 28 (2020)
  - P. Banerjee at al, SciPost Phys. 9, 27 (2020)
  - R. Boncianiet al, arXiv:2106.13179

A. Masiero, P. Paradisi, M. Passera, PRD 102 (2020) 075013
P.S. Bhupal Dev et al., JHEP05(2020)53

- Study on New Physics contaminations: MUonE is not vulnerable.

Conclusions

https://web.infn.it/MUonE/

- The new method proposed by MUonE to determine a_μ^{HLO} is independent and competitive with the latest evaluations.

- A parasitic Run will be performed at CERN to test the DAQ system in October-November 2021.

- A Test Run of 3 weeks is foreseen at CERN in 2022.
  The aim of the Test Run will be to verify the detector design, to evaluate the analysis strategy, study the systematic effects and possibly to perform a measurement of $\Delta\alpha_{\mathrm{lep}}(\mathrm{t})$.

- Beyond the Test Run: we are planning a first measurement to be performed in 2023-24: a ~2% (stat) measurement of a_μ^{HLO} can be achieved by adding 10 stations to the existing prototype, with a running time of 4 months.

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