The MUonE experiment

A high precision measurement of $a_\mu^{\text{HLO}}$ with a 150 GeV $\mu$ beam on $e^-$ target at CERN

G. Venanzoni
INFN-Pisa
Reference papers

A new approach to evaluate the leading hadronic corrections to the muon $g$-2

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Measuring the leading hadronic contribution to the muon $g$-2 via $\mu e$ scattering


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Muon g-2: summary of the present status

• E821 experiment at BNL has generated enormous interest:

\[ \alpha^{E821} = 11659208.9(6.3) \times 10^{10} \text{ (o.54 ppm)} \]

• Tantalizing \( \sim 3\sigma \) deviation with SM (persistent since >10 years):

\[ \alpha^{SM} = 11659182.3(4.3) \times 10^{10} \]

\[ \alpha^{E821} - \alpha^{SM} \sim (26.8 \pm 7.6) \times 10^{10} \text{ (3.5 \sigma)} \]


• Current discrepancy limited by:
  • Experimental uncertainty \( \rightarrow \) New experiments at FNAL and J-PARC \( \times 4 \) accuracy
  • Theoretical uncertainty \( \rightarrow \) limited by hadronic effects

\[ \alpha^{SM} = \alpha^{QED} + \alpha^{HAD} + \alpha^{Weak} \]

Hadronic Vacuum polarization (HLO)

\[ a_{\mu}^{HLO} = (693.1 \pm 3.4) \times 10^{-10} \]

\[ \delta a_{\mu}/a_{\mu} \sim 0.5\% \rightarrow 0.2\% \]

G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018
\(a_\mu^{\text{HLO}}\) calculation, traditional way: time-like data

[C. Bouchiat, L. Michel, '61; N. Cabibbo, R. Gatto 61; L. Durand '62-63; M. Gourdin, E. De Rafael, ’69; S. Eidelman F. Jegerlehner ’95, . . . ]

- Optical theorem and analyticity:

\[
\sigma(s)_{(e^+e^-\rightarrow \text{had})} = \frac{4\pi}{s} \text{Im} \Pi_{\text{hadron}}(s)
\]

\[
a_\mu^{\text{HLO}} = \frac{1}{4\pi^3} \int_{4m^2_\pi}^{\infty} ds \, K(s) \cdot \sigma(s)_{(e^+e^-\rightarrow \text{had})}
\]

- The main contribution is in the highly fluctuating low energy:

\[
K(s) = \int_0^1 dx \frac{x^2(1-x)}{x^2 + (1-x)(s/m^2)} \sim \frac{1}{s}
\]

The enhancement at low energy implies that the \(\rho \rightarrow \pi^+\pi^-\) resonance is dominating the dispersion integral (\(\sim 75\%\)). Current precision at 0.6\% \(\rightarrow\) need to be reduced by a factor \(\sim 2\).

G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018

\[\Delta^\text{SM-BNL} \sim 4\% \text{ of } a_\mu^{\text{HLO}}\]
Alternative approach: $a_\mu^{HLO}$ from space-like region


\[
a_\mu^{HLO} = \frac{\alpha}{\pi} \int_0^1 dx \left( 1 - x \right) \cdot \Delta \alpha_{had} \left( -\frac{x^2 m^2_\mu}{1 - x} \right)
\]

\[
t = \frac{x^2 m^2}{x - 1} \quad 0 \quad t < +
\]

\[
x = \frac{t}{2m^2} \left( 1 - \sqrt{1 - \frac{4m^2}{t}} \right); \quad 0 \quad x < 1;
\]

- $a_\mu^{HLO}$ is given by the integral of the curve (smooth behaviour)
- It requires a measurement of the hadronic contribution to the effective electromagnetic coupling in the space-like region $\Delta \alpha_{had}(t)$ ($t = q^2 < 0$)
- It enhances the contribution from low $q^2$ region (below 0.11 GeV$^2$)
- Its precision is determined by the uncertainty on $\Delta \alpha_{had}(t)$ in this region

G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018
Experimental approach:

Use of a 150 GeV $\mu$ beam on Be target at CERN (elastic scattering $\mu e \rightarrow \mu e$) to get $\Delta\alpha_{\text{had}}(t<0)$

$$|\frac{(t)}{0}|^2 = |\frac{1}{1-(t)}|^2$$

Why measuring $\Delta\alpha_{\text{had}}(t)$ with a 150 GeV $\mu$ beam on $e^-$ target?

It looks an ideal process!

- $\mu e \to \mu e$ is pure $t$-channel (at LO)
- It gives $0<-t<0.161$ GeV$^2$ ($0<x<0.93$)
- The kinematics is very simple: $t=-2m_eE_e$
- High boosted system gives access to all angles ($t$) in the cms region
  \[ \theta_{e,\text{LAB}}<32 \text{ mrad (} E_e>1 \text{ GeV)} \]
  \[ \theta_{\mu,\text{LAB}}<5 \text{ mrad} \]
- It allows using the same detector for signal and normalization
- Events at $x \approx 0.3$ ($t \approx 10^{-3}$ GeV$^2$) can be used as normalization ($\Delta\alpha_{\text{had}}(t) \approx 10^{-5}$)
MUonE: signal/normalization region

\[ \frac{N_{\text{data}}(t_i)}{N_{\text{MC}}^0(t_i)} = \frac{N_{\text{data}}(t_i)}{N_{\text{data}}^{\text{norm}}} \times \frac{N_{\text{MC}}^{\text{0, norm}}(t_i)}{N_{\text{MC}}^0(t_i)} \approx 1 \times 2 \left( N_{\text{lep}}(t_i) + N_{\text{had}}(t_i) \right) \]

\[ a_\mu^{\text{HLO}} \text{ at } 0.3\% \rightarrow \text{These two ratios should be known at } 10^{-5} \]

G. Venanzoni, Pisa, 5 June 2018
Statistical reach of MUonE on $a_{\mu}^{\text{HLO}}$
(2 years of data taking at $1.3 \times 10^7 \mu/s$)

A $0.3\%$ stat error can be achieved on $a_{\mu}^{\text{HLO}}$ in 2 years of data taking with $\sim 10^7 \mu/s$ ($4 \times 10^{14} \mu$ total)
Measuring e- and muon angle:
Repetition (x50) of this single module

~1cm Be Target
State-of-art Silicon detectors
hit resolution ~10 μm
expected angular resolution ~ 10 μm / 0.5 m = 0.02 mrad

G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018
Elastic scattering in the $(\theta_e, \theta_\mu)$ plane

Coplanarity of the momentum vectors and angular kinematical constraint

Muon beam momentum $= 150$ GeV

$x = 0.93, E_e = 130.7$ GeV

$x = 0.9, E_e = 88.5$ GeV

$x = 0.7, E_e = 55.0$ GeV

$x = 0.6, E_e = 48$ GeV

$x = 0.5, E_e = 50.5$ GeV

$x = 0.4, E_e = 2.9$ GeV

$x = 0.3, E_e = 1.4$ GeV

$x = 0.2, E_e = 0.5$ GeV

$x = 0.1, E_e = 0.1$ GeV

G. Venanzoni, Pisa, 5 June 2018
Systematics

1. Multiple scattering
2. Tracking (alignment & misreconstruction)
3. PID
4. Knowledge of muon momentum distribution
5. Background
6. Theoretical uncertainty on the mu-e cross section (see later)

7. ...

All the systematic effects must be known to ensure an error on the cross section < 10ppm
Multiple Scattering studies: 
Results from Test Beam 2017

Check GEANT MSC prediction and populate the 2D ($\theta_e$, $\theta_\mu$) scattering plane

- 27 Sep-3 October 2017 at CERN "H8 Beam Line"
- Adapted UA9 Apparatus
- Beam energy: e- of 12/20 GeV; $\mu$ of 160 GeV
- $10^7$ events with C targets of different thickness (2,4,8,-20mm)

Adapted UA9 apparatus

5 Si planes: 2 before and 3 after the target, 3.8x3.8 cm$^2$ intrinsic resolution ~$100 \mu$rad

G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018
MS studies with $e^-$

20mm, 12 GeV

$\chi^2/\text{NDF} = 94/15$
$p_0 = 0.998 \pm 0.001$

$\chi^2/\text{NDF} = 30/19$
$p_0 = 1.001 \pm 0.001$

+2%  
-2%
Detector optimization

- Target thickness (10mm Be default)
- Silicon sensors (type, material)
- Number of tracking stations per unit (3-4)
- Dimension of apparatus
- Calorimetry/PID
- Trigger/DAQ
- …
Silicon detectors survey

In HEP experiments a large effort is needed to produce new detectors. Most of the effort goes into the design, production and qualification of the front-end electronics, which is also expensive. Using already-existing front-ends is a good way to contain cost and risks.

Here a few detectors are compared. New detector productions could be easily incremented by a few units to cover for MuonE needs, but it is also possible that older detectors (e.g. APV25) can be adapted, possibly with a new sensor production.

For simplicity, from here on I am going to focus on a subset of these detectors.

<table>
<thead>
<tr>
<th>Technology</th>
<th>ALICE Upg Inner</th>
<th>ALICE Upg Outer</th>
<th>CMS Upg 2S</th>
<th>2×CMS Upg 2S</th>
<th>CMS Upg PS</th>
<th>CMS Upg Pixel</th>
<th>2×CMS Current</th>
<th>Mimosa26 Technology</th>
<th>LHCb VELO-pix</th>
</tr>
</thead>
<tbody>
<tr>
<td>active x [cm]</td>
<td>27</td>
<td>21</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>33</td>
<td>10</td>
<td>1.06</td>
<td>4.246</td>
</tr>
<tr>
<td>active y [cm]</td>
<td>1.5</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>44.2</td>
<td>10</td>
<td>2.12</td>
<td>1.408</td>
</tr>
<tr>
<td>pixel size x [µm]</td>
<td>30</td>
<td>30</td>
<td>90</td>
<td>90</td>
<td>100</td>
<td>50</td>
<td>90</td>
<td>18.4</td>
<td>55</td>
</tr>
<tr>
<td>pixel size y [µm]</td>
<td>30</td>
<td>30</td>
<td>50000</td>
<td>90</td>
<td>1400</td>
<td>50</td>
<td>50000</td>
<td>18.4</td>
<td>55</td>
</tr>
<tr>
<td>σx [µm]</td>
<td>2</td>
<td>2</td>
<td>26</td>
<td>26</td>
<td>29</td>
<td>7</td>
<td>18</td>
<td>3.2</td>
<td>12</td>
</tr>
<tr>
<td>σy [µm]</td>
<td>2</td>
<td>2</td>
<td>14434</td>
<td>26</td>
<td>404</td>
<td>7</td>
<td>18</td>
<td>3.2</td>
<td>12</td>
</tr>
<tr>
<td>Material [x/X₀]</td>
<td>0.3%</td>
<td>0.8%</td>
<td>2.3%</td>
<td>4.5%</td>
<td>3.8%</td>
<td>2.0%</td>
<td>4.5%</td>
<td>0.10%</td>
<td>0.94%</td>
</tr>
<tr>
<td>Sensor mat. [x/X₀]</td>
<td>0.3%</td>
<td>0.8%</td>
<td>0.3%</td>
<td>0.6%</td>
<td>3.8%</td>
<td>2.0%</td>
<td>0.6%</td>
<td>0.10%</td>
<td>0.94%</td>
</tr>
</tbody>
</table>
2018 Test run:
Full scale prototype (2 modules) on M2 muon beam at CERN behind Compass

- Study of the detector performance: signal/background; tracking efficiency; understand the systematics

- It takes data since April 9
- 300M events already collected
Theory

- **QED NLO MC** generator with full mass dependence has been developed and is currently under use (Pavia group)
- Results obtained for the **NNLO** box diagrams contributing to mu-e scattering in QED (Padova group)

Master integrals for the NNLO virtual corrections to \( \mu e \) scattering in QED: the planar graphs

Pierpaolo Mastrolia,\(^a\,b\) Massimo Passera,\(^b\) Amedeo Primo,\(^a\,b\) Ulrich Schubert\(^c\)

Master integrals for the NNLO virtual corrections to \( \mu e \) scattering in QED: the non-planar graphs

Stefano Di Vita,\(^a\) Stefano Laporta,\(^b\,c\) Pierpaolo Mastrolia,\(^b\,c\) Amedeo Primo,\(^d\) Ulrich Schubert\(^e\)

1806.08241

- An unprecedented precision challenge for theory: a full NNLO MC generator for \( \mu\)-e scattering (10\(^{-5}\) accuracy)

G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018
Theory: international community!


- 2018, Feb 19-23: A Topical workshop at MIPT, Mainz https://indico.mitp.uni-mainz.de/event/128/

- 2019, Feb 4-7: Workshop on “Theory for muon-electron scattering @ 10ppm” in Zurich
Status of the Collaboration and plans

• Collaboration is growing and interest from International groups from CERN, Poland, Russia (Novosibirsk), UK, USA (Virginia) has been expressed.

• Results so far encouraging; we are part of “Physics Beyond Collider” process at CERN (http://pbc.web.cern.ch/); we had a very good PBC review on March 2018.

• We aim to write a LoI in 2019; to construct and install the detector (funding allowing) in 2020-2021, and to start data taking in 2021/22 for 2 years (with a pilot run first)
Conclusion

• Exciting times for the muon g-2!
• **Alternative/competitive determinations of** $a_{\mu}^{\text{HLO}}$ **are essential:**
  • Time-like (dispersive) approach
  • Lattice
  • Space-like approach (MUonE)

• **Progress on MUonE:**
  • Analysis of MS 2017 TB data
  • Detector optimization
  • Silicon detector procurement
  • Progress on the Theory side
  • Test run in 2018; planned tests for 2019
  • Growing interest from both experiment and theory community
  • Lol planned for 2019; if approved/funded start of data taking in 2021/22 for 2 years (with a pilot run first)
MUonE Collaboration (in progress)

THE END
SPARE
EXPERIMENTAL SETUP

Picture taken on 4/8/18
Test Beam 2018

- Setup mounted in April 3-9;
- It take data since April 9
- 300M events already collected (>1TB);
- Rate: 5Mev/day (20GB/day)
Outline

- Muon g-2: summary of the present status
- The MUonE proposal: a novel approach to compute $a_\mu^{HLO}$ in the space-like region with $\mu e \rightarrow \mu e$ at CERN
- Some recent progress
- Plans & conclusions
Plans for 2018

Build up and test a full scale prototype (2 modules).

• Run of a 2 full scale modules on a muon beam on M2 (behind COMPASS) from April/May
• Study of the detector performance: signal/background; tracking efficiency; understand the systematics
• Data taking is going on!

G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018
Measurement of $\Delta\alpha_{\text{had}}(t)$ spacelike at LEP

- $\Delta\alpha_{\text{had}}(t)$ ($t<0$) has been measured at LEP using small angle Bhabha scattering

$$f(t) = \frac{N_{\text{data}}(t)}{N_{\text{MC}}^0(t)} \propto \left( \frac{1}{1 - \Delta\alpha(t)} \right)^2.$$  

Accuracy at per mill level was achieved!


- For low t values ($\leq 0.11$ GeV$^2$) and higher precision ($\sim 10^{-5}$) as in our case a different approach is needed!


Detector considerations

• Modular apparatus: 60 layers of ~1 cm Be (target), each coupled to ~0.5 m distant Si (0.3 mm) planes. It provides a 0.02 mrad resolution on the scattering angle.

• The $t=q^2<0$ of the interaction is determined by the electron (or muon) scattering angle (à la NA7).

• ECAL and $\mu$ Detector located downstream to solve PID ambiguity below 5 mrad. Above that, angular measurement gives correct PID.

• It provides uniform full acceptance, with the potential to keep the systematic errors at $10^{-5}$ (main effect is the multiple scattering for normalization which can be studied by data).

• Statistical considerations show that a 0.3% error can be achieved on $a_{\mu}^{\text{HLO}}$ in 2 years of data taking with $\sim 10^7 \mu/s$ ($4\times 10^{14} \mu$ total).
Muon beam M2 at CERN

“Forty years ago, on 7 May 1977, CERN inaugurated the world’s largest accelerator at the time – the Super Proton Synchrotron”.

Table 3
Parameters and performance of the 160 GeV/c muon beam.

<table>
<thead>
<tr>
<th>Beam parameters</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam momentum ( (p_\mu)/(p_\pi) )</td>
<td>( (160 \text{ GeV/c})/(172 \text{ GeV/c}) )</td>
</tr>
<tr>
<td>Proton flux on T6 per SPS cycle</td>
<td>( 1.2 \cdot 10^{13} )</td>
</tr>
<tr>
<td>Focussed muon flux per SPS cycle</td>
<td>( 2 \cdot 10^{8} )</td>
</tr>
<tr>
<td>Beam polarisation</td>
<td>( (-80 \pm 4)% )</td>
</tr>
<tr>
<td>Spot size at COMPASS target ( (\sigma_x \times \sigma_y) )</td>
<td>( 8 \times 8 \text{ mm}^2 )</td>
</tr>
<tr>
<td>Divergence at COMPASS target ( (\sigma_x \times \sigma_y) )</td>
<td>( 0.4 \times 0.8 \text{ mrad} )</td>
</tr>
<tr>
<td>Muon halo within 15 cm from beam axis</td>
<td>16%</td>
</tr>
<tr>
<td>Halo in experiment ( (3.2 \times 2.5 \text{ m}^2) ) at (</td>
<td>x, y</td>
</tr>
</tbody>
</table>

\( I_{\text{beam}} > 10^7 \text{ muon/s}, \ E_\mu = 150 \text{ GeV} \)

G. Venanzoni, Pisa, 5 June 2018
8mm, 12 GeV
Report of A. Magnon (MUonE referee in PBC)
2 March 2018

- Expect a lot of physics input from these tests
  Hope we can run at (close) to nominal $\mu$ Flux

- Concerning the final project for High precision measurement of $a_\mu^{\text{HLO}}$
  Certainly very challenging
  I (Alain Magnon) DO NOT SEE a priori showstopper(s)
Detector optimization

Si detectors

target

G. Venanzoni, Pisa, 5 June 2018
Diffusion angle [-2,2] mrad

\[ \chi^2/\text{NDF} = 62/15 \]
\[ p_0 = 1.001 \pm 0.001 \]

Diffusion angle [-0.5,0.5] mrad

\[ \chi^2/\text{NDF} = 55/19 \]
\[ p_0 = 1.001 \pm 0.001 \]
Test Beam setup and target

Thanks to the UA9 Collaboration
(particularly M. Garattini, R. Iaconageli, M. Pesaresi), J. Bernhard
Resolution dominated by MS up to 10~100 GeV/c

- Resolution on scattering angle assumptions:
  - 2 measurement plane 0.5 m apart
  - Scattering on:
    - No plane (ideal resolution)
    - First detector plane (pure tracker resolution)
    - First plane + ½ Be target (includes “average” MS in target)
  - Core of MS only considered (no tails)

\[ \Delta \theta = \Delta \theta_i + \Delta \theta_{MS} \]

\[ \Delta \theta_i = \frac{\Delta x \sqrt{2}}{0.5 \text{ m}} \]

\[ \Delta \theta_{MS} = \frac{13.6}{p/\text{MeV}} \sqrt{m(1 + 0.038 \ln m)} \]

Scattering material: first layer only

\[ m = \left( \frac{x}{X_0} \right)_{\text{det}} \]
Detector integration time

- Hybrid pixels & strips for (HL-)LHC: 25 ns
- ALPIDE: 1 µs
- Mimosa26: 112 µs

Expected pile-up events (per 40MHz)

\[ N_\mu = r \times \tau \]

- e.g. \( N_\mu = 40 \text{ MHz} \times 25 \text{ ns} = 1 \)
- e.g. \( N_\mu = 40 \text{ MHz} \times 1 \text{ µs} = 40 \)

G. Venanzoni, Pisa, 5 June 2018
"The scatter distribution of the measured polar angles of the right and left-going particles ($\theta_R, \theta_L$). Our estimate of $q^2$ was made from the point on the theoretical kinematic curve nearest to these angle coordinates".
“The pion form factor has been measured in the space-like $q^2$ region 0.014 to 0.26 (GeV/c)$^2$ by scattering 300 GeV pions from the electrons of a liquid hydrogen target”.

“The $q^2$ variable for the final sample was determined from the angles alone, up to the kinematic ambiguity which was resolved using the shower detectors. In this procedure the only rejection criterion involving the momenta was a cut against electrons of less than 1 GeV/c”.
"The scatter distribution of the measured polar angles of the right and left-going particles \((\theta_R, \theta_L)\). Our estimate of \(q^2\) was made from the point on the theoretical kinematic curve nearest to these angle coordinates”.

"A fraction of the hadronic background was rejected by requiring coplanarity of the incident and scattered tracks"
Last module of the detector

Measure both the electron angle and $E_e$ to define the reference, calibration curve. Detailed check of GEANT predictions.
Fraction of $a_\mu^{HLO}$ covered

87% of $a_\mu^{HLO}$ covered with $P_\mu=150$ GeV

G. Venanzoni, Pisa, 5 June 2018
Fraction of $a_\mu^{HLO}$ covered

87% of $a_\mu^{HLO}$ covered with $P_\mu=150$ GeV

(courtesy of M. Incagli)

G. Venanzoni, Pisa, 5 June 2018
The silicon detectors

Sensors developed for AGILE, being used by LEMMA

Table 1
Main features of the AGILE silicon detector

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension (cm²)</td>
<td>9.5 × 9.5</td>
</tr>
<tr>
<td>Thickness (µm)</td>
<td>410</td>
</tr>
<tr>
<td>Readout strips</td>
<td>384</td>
</tr>
<tr>
<td>Readout pitch (µm)</td>
<td>242</td>
</tr>
<tr>
<td>Physical pitch (µm)</td>
<td>121</td>
</tr>
<tr>
<td>Bias resistor (MΩ)</td>
<td>40</td>
</tr>
<tr>
<td>AC coupling Al resistance (Ω/cm)</td>
<td>4.5</td>
</tr>
<tr>
<td>Coupling capacitance (pF)</td>
<td>527</td>
</tr>
<tr>
<td>Leakage current (nA/cm²)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Daniela Lietti, PhD thesis. VISION: a Versatile and Innovative SIllicON tracking system


G. Venanzoni, Fermilab, 10 April 2018
Experimental setup location

Site inspection in COMPASS on 11/10/2017

Counting room quite far from experimental site: DAQ PC near setup → “short” optical fiber from crate VME to DAQ PC, then ethernet cable from DAQ PC to counting room

G. Venanzoni, g-2 Coll Meeting 22 March 2018
Timelike data aiming at 0.2% on $a_\mu^{\text{HLO}}$?

- Not an easy task!
  - >30 channels to keep under control (at (sub)percent level)
  - Local discrepancies in main channels ($2\pi$ (KLOE/Babar), $K^+K^-$ CMD2/Babar)
  - Isospin corrections for not measured channels
  - Treatment of narrow resonances? (See F. Jegerlehner, ArXiv:1511.04473)

An independent/complementary approach is highly desirable!

M. Davier, TAU16 WS

G. Venanzoni, $\mu$-e Theory Workshop, Padova, 4 September 2017
Lattice-QCD progress on $a_\mu^{HVP}$

- Can calculate nonperturbative vacuum polarization function $\Pi(Q^2)$ directly in lattice QCD from simple 2-point correlation function of EM quark current [Blum, PRL 91 (2003) 052001]

- Several ongoing lattice efforts yielding new results since ICHEP 2014 including:

  (1) First calculation of quark-disconnected contribution [RBC/UKQCD, PRL 116, 232002 (2016)]

  (2) Second complete calculation of leading-order $a_\mu^{HVP}$ [HPQCD, arXiv:1601.03071]

  - First to reach precision needed to observe significant deviation from experiment

  - ~1% total uncertainty by 2018 possible

  - Sub-percent precision will require inclusion of isospin breaking & QED, and hence take longer
**However**: Recent Lattice evaluation

**Hadronic vacuum polarization contribution to the anomalous magnetic moments of leptons from first principles**


(Budapest-Marseille-Wuppertal collaboration)

\[ a_{\mu}^{\text{LO-HVP}} \times 10^{10} \]

- **This work**
- HPQCD 16
- ETM 14

- Jegerlehner 17
- Davier 16
- Hagiwara 16

**error~2.7%**

14 Nov

G. Venanzoni, Seminar at BNP, Novosibirsk  25 January 2018
\[ a_{\mu}^{\text{LO-HVP}} = 711.0(7.5)(17.3) \times 10^{-10} \]

\( \text{stat} \quad \text{syst} \quad 2.7\% \)

(NP). Using the SM contributions summarized in [8], we find \( a_{\mu,\text{noNP}}^{\text{LO-HVP}} = (720.0 \pm 6.8) \times 10^{-10} \). The errors on the lattice results, which are in the range of 2.0 to 4.1\% are substantially larger than those of the phenomenological approach. Our result for \( a_{\mu}^{\text{LO-HVP}} \) is larger than those of the other lattice calculations and in slight tension with the one from HPQCD [33] which is 1.9\( \sigma \) away. A more detailed flavor-by-flavor comparison is given in [45]. However, our result is consistent with those from phenomenology within about one standard deviation, as well as with \( a_{\mu,\text{noNP}}^{\text{LO-HVP}} \). Thus, one will have to wait for the next generation of lattice QCD calculations to confirm or infirm the larger than 3\( \sigma \) deviation between the measurement of \( a_{\mu} \) and the prediction of the SM based on phenomenology.
Experimental Setup

Scintillators: 2 100 x 100 mm²
Silicon detectors: 12 XY planes
  2 UV plane ±45°

Need 3 stereo views to resolve ambiguities
Il readout

Readout electronics
- Zero suppression mode
- 1 ADC board per 4 moduli single side
- 1 VME Readout Board per leggere gli ADC e immagazzinare i dati durante la spill
- Readout speed $\rightarrow$ 6 kHz $\rightarrow$ questo numero può salire a 15 kHz se ognuno dei 3 ASIC che leggono una vista è letto in modo indipendente (e non in una daisy chain a 3 come succede adesso)
  $\rightarrow$ è possibile solo costruendo moduli nuovi

Abbiamo materiale per costruire ulteriori 10 viste x-y
Prospect for 2018 run

**Silicon beam chambers:**

- 4 moduli X-Y con i rivelatori single side di AGILE $\rightarrow$ 9.5x9.5 cm$^2$ con strip a passo 242 $\mu$m $- 1$ strip floating $\rightarrow$ risoluzione spaziale di 30 $\mu$m
- 4 moduli X-Y richiedibili a INFN Bari (gruppo Fermi) $\rightarrow$ rivelatori single side di 8.75x8.75 cm$^2$ con strip a passo 228 $\mu$m
- In costruzione: 5 moduli X-Y per LEMMA con i rivelatori single side di AGILE


Daniela Lietti, PhD thesis. VISION: a Versatile and Innovative SIlicON tracking system
Some numbers:

- 60 cm total Be target \( (2X_0) \) segmented in 60 stations with 1 cm target \( (0.03 X_0) \)
- ~30 m total detector length
- 10x10 cm\(^2\) silicon detectors
- Resolve each \( \mu, e \) track with uniform efficiency
- Best possible resolution on \( \theta_\mu \) (<5 mrad), \( \theta_e \) (<50 mrad)
- \( \mu \) rate: ~60 MHz (peak) → 15 MHz (averaged)
- \( \mu \) separation: 17 ns (peak) → 68 ns (averaged)
- Collect \( 4 \times 10^{12} \) events with \( E_e > 1 \text{GeV} \) in ~2 years
- Scattering probability \( (E_e > 1 \text{GeV}) \): \( 1.7 \times 10^{-4} \text{cm} \)
- Scattering event rate \( (E_e > 1 \text{GeV}) \): ~10 kHz per station (peak); 2.5 (avg)
- Scattering separation \( (E_e > 1 \text{GeV}) \): 100 \( \mu \)s per station
(Preliminary) Analysis of Test Beam data

First $\mu$-e elastic events!

- Elasticity $E_\mu = 160$ GeV
- Test Beam preliminary data 2017

G. Venanzoni, Pisa, 5 June 2018
Plans

• **2018-2019**
  - Detector optimization studies: simulation; Test Run at CERN (2018); Mainz with 1GeV e- (2019); Fermilab with 60 GeV μ (2019)
  - Theoretical studies
  - Set up a collaboration
  - Letter of Intent to the SPSC

• **2020-2021**
  - Detector construction and installation
    (a staged version of the detector may be)

• **2022–2024**
  - Data taking: staged detector for a first (pilot) run +2 years with full detector

LHC schedule