MUonE

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

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on behalf of the proponents

“The closer you look the more there is to see” (F. Jegerlehner)

PBC Workshop, CERN 16 January 2019
Outline

• A (brief) Reminder on MUonE proposal
• Some recent progress
• Plans
• Conclusions
Muon g-2: summary of the present status

- ~3.5σ discrepancy between $a_\mu^{E821}$ and $a_\mu^{SM}$
- New $(g-2)_\mu$ experiments at Fermilab (E989) and JPARC (E34) → First result from E989 expected in 2019
- If E989 confirms E821 (with full stat) → $a_\mu^{E821} - a_\mu^{SM} \sim 7\sigma$ → New Physics?
- Discrepancy limited by the uncertainty on the theory side (hadronic effects)

→ Different methods to control the theory very important!

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MUonE proposal: $a_\mu^{\text{HLO}}$ from space-like region


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

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

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

MUonE stat. accuracy: $\delta a_\mu^{\text{HLO}} \approx 0.3$

$a_\mu^{\text{HLO}}$ is given by the integral of the curve

Angular measurement $t=f(\theta_e; \theta_\mu)$

$\Delta \alpha_{\text{had}}(t<0)$ from $N^{\mu e}_{\text{signal}}(t) / N^{\mu e}_{\text{norm}}$ at 10ppm
Detector concept

Repetition (x60) of this single module
(~ 40-60 m total length)

~50-100 cm

10 cm

~1cm Be Target

State-of-art Silicon detectors

hit resolution ~20 μm

Expected angular resolution ~ 20 μm / 1m = 0.02 μrad

At the end ECAL and Muon Filter for PID

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Last 2 years progress

1. Multiple scattering studies (TB 2017)
2. Test beam at M2 in 2018
3. Baseline Si detector defined (CMS)
4. LO and NLO Studies
5. Location at EHN2
6. Theory progress
Test Beam 2017 at H8: the setup

- We used the UA9 tracking system to record scattering data.
- Alignment, tracking, pattern recognition, comparison with Geant4 simulation.
- The goal: reach ~1% in the core of the MS distributions and few percent on the tails.

Adapted UA9 apparatus:
- 5 Si planes: 2 before and 3 after the target, 3.8x3.8 cm² intrinsic angle resolution ~100 μrad.

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Agreement in the core region (90% of events) ~ 1%; outside few %
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Parametrization of the deflection angle: telescope

\[ f_{\text{telescope}}(\theta) = N \left( (1 - a) \frac{1}{\sqrt{2\pi} \sigma_G} e^{-\frac{(\theta - \mu)^2}{2\sigma_G^2}} + a \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sqrt{\nu\pi\sigma} \Gamma\left(\frac{\nu}{2}\right)} \left( 1 + \frac{(\theta - \mu)^2}{\nu\sigma^2} \right)^{-\frac{\nu+1}{2}} \right) \]

[N. Berger et al. JINST 9 (2014) P07007]

Similar results for y-view

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Parametrization of the deflection angle: telescope+target

\[ f(\theta) = \int f_{\text{telescope}}(\theta - \theta') f_{\text{target}}(\theta') d\theta' \]

Parameters fixed to alignment data

Same parametrization as \( f_{\text{telescope}} \)

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Data-MC difference \( \sim 1\text{-}2\% \) for \( \sigma_G \); \( \sim 5\text{-}10\% \) for \( \sigma_T \) (systematic errors of \( \sim 1\text{-}2\% \) not included)

Paper is in progress
Test beam 2018

- A full scale prototype has been located downstream COMPASS, behind the Tungsten hadrons filter.
- Aim of the measurement campaign: muon – electron elastic scattering with high statistics
  - Using muons from pions decays (hadron beam) with an estimated beam momentum $p = (187 \pm 7)$ GeV
  - To measure the correlation between the scattering angles: muon angle vs the electron angle; use of the e- Energy
- The detector consists of:
  - Tracking system: AGILE silicon strip sensors: 400 $\mu$m thick, single sided, about 40 $\mu$m intrinsic hit resolution.
  - Electromagnetic calorimeter: $3 \times 3$ cell matrix.

Data analysis in progress

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Effect of the resolution: GEANT4 (40μm hit resolution)

angle_μ vs angle_e

Signal
Background

Pair production

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Effect of the resolution: GEANT4
(10\mu m hit resolution)

angle_\mu vs angle_e

Signal
Background

Pair production

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CBC3 based CMS detector

Hit resolution $\sim 18 \, \mu m$

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«Blind» Extraction of $a_\mu^{HLO}$ (LO)

$\theta_\mu$ (rad)

Here is $\alpha(t)$

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

Last iteration consistent (at 0.3σ) with the input value for $a_\mu^{HLO}$

X = 0.377952 - 0.931984

From timelike data:
$\Delta a_\mu^{LO} = 563.4 \pm 2.8 \times 10^{-10}$

Integral After last iteration:
565.5 $\pm$ 7.8 $\times$ 10^{-10}

Precision 1.37%
Compatible with 0.4%

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NLO Studies

- MC NLO available (Pavia Theory group)
- An elasticity region can be defined (containing 95% of the events).
- Sensitivity to the hadronic contribution to the running of $\alpha(t)$ is the expected one.
- The total selection efficiency will depend on additional cuts (coplanarity, energy threshold, etc) needed.
Possible location at CERN M2

- Between BSM and COMPASS

1/ μ-e setup upstream of present COMPASS experiment, i.e. within M2 beam-line

- More upstream of Entrance Area of EHN2 (Proposed by Johannes B. & Dipanwita B.)
  - Pro: Could allow running μ-e/μ-\(p_{\text{Radius}}\) in parallel.
  - Questions: will require displacements (also removal) of some M2 components.
  - Beam(s) compatibility for μ-e & μ-\(p_{\text{Radius}}\): Optic’s wise looks OK (see Add. Sl.14 from D.B.)

Beam Synergy/sharing at M2 under study (thanks to A. Magnon)
Theory

- QED NLO MC generator with full mass dependence has been developed and is currently under use (Pavia group): M. Alacevich, *et al* arXiv:1811.06743.


- Next Theory workshop: Feb 4-7 2019: “Theory for muon-electron scattering @ 10ppm” in Zurich (orgs: A. Signer and Y. Ulrich)

An unprecedented precision challenge for theory: a full NNLO MC generator for μ-e scattering (10⁻⁵ accuracy)

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Plans

• 2019
  – Detector optimization /test beam/full MC simulation
  – Letter of Intent to the SPSC

• 2020-2021
  – Detector construction and installation
    (request a pilot run in 2021 in the time window not yet allocated)

• 2022–2024
  – data taking to measure $a_{\mu}^{\text{HLO}}$ at few per mill error
    first run with scaled detector and reduced accuracy (~1%?)

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Conclusion

• Exciting times for the muon g-2. New result from the E989 experiment at Fermilab expected soon

• Very important: theory “under control” (especially strong interaction)

• Progress on MUonE:
  • Analysis of Multiple Scattering TB data. Paper is almost ready
  • Analysis of 2018 Test Run @M2 in progress
  • Baseline design: Silicon detector: CMS
  • Progress on NLO
  • Location of MUonE at EHN2
  • Progress on Theory side
  • LoI planned for 2019
THE END

(Thanks to J. Berhnard, L. Gatignon and A. Magnon for many useful discussions and work)
MUonE Collaboration (in progress)

Suitable sensors and ASICs

• Requirements:
  – Dimensions: 10 cm × 10 cm
  – Single hit resolution: r ≤ 10 μm
  – Fast timing (25 ns).
  – Minimal thickness: d ≤ 300 μm

• Possible implementation:
  – strip pitch p ≤ 50μm and floating electrodes
    charge sharing to get a resolution better than
    the geometrical σ=p/sqrt(12), depending on
    S/N
  – 1028 channel hybrid per sensor single sided