g-2/EDM at J-PARC and synergy of tracking software development

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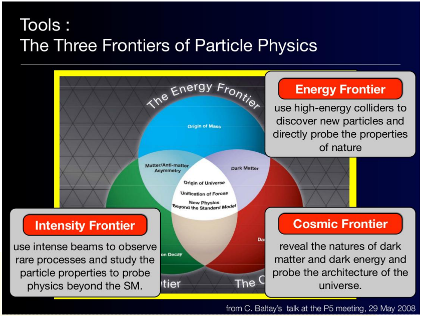
Outline

Beyond the Standard Model (BSM)

The discovery of the Higgs boson at the LHC in 2012 provided the missing piece in the Standard Model (SM) to explain electroweak symmetry breaking.

However there remain many shortcomings in the SM's description of nature, notably :

the lack of a dark-matter candidate;
no explanation for the observed matter antimatter asymmetry in the universe;
no quantum theory of gravity;
and no explanation for smallness of neutrino masses, $\cdots$



$\Rightarrow$ All these phenomena highlight the need for physics beyond the SM (BSM) and many of these models predict charged lepton flavour violation (CLFV) and $(g-2)_\mu$ contributions

DNA of New Physics

W. Altmannshofer, A.J. Buras, S. Gori, P. Paradisi and D.M. Straub

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\mathrm{CP}}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

These are a subset of a subset listed by Buras and Girrbach
MFV, CMFV, 2HDM$_{\overline{\mathrm{MFV}}}$, LHT, SM4, SUSY flavor. SO(10) – GUT, SSU(5)$_{\mathrm{HN}}$, FBMSSM, RHMFV, L-R, RS$_0$, gauge flavor, ...

The pattern of measurement:
★★★ large effects
★★ visible but small effects
★ unobservable effects
is characteristic,
often uniquely so,
of a particular model

GLOSSARY	
AC [10]	RH currents & U(1) flavor symmetry
RVV2 [11]	SU(3)-flavored MSSM
AKM [12]	RH currents & SU(3) family symmetry
δLL [13]	CKM-like currents
FBMSSM [14]	Flavor-blind MSSSM
LHT [15]	Little Higgs with T Parity
RS [16]	Warped Extra Dimensions

⇒ good candidates to probe NP :
Lepton Flavor Violation (LFV) of Charged Leptons, $(g-2)_\mu$, $\cdots$

$(g-2)_\mu$

Particle dipole moments

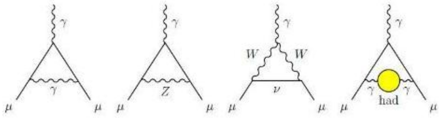
Hamiltonian of spin 1/2 particle includes

$$\mathcal{H} = -\vec{\mu}\cdot\vec{B} - \vec{d}\cdot\vec{E}$$

Magnetic dipole moment $\vec{\mu} = g\left(\frac{q}{2m}\right)\vec{s}\,,$

Electric dipole moment $\vec{d} = \eta\left(\frac{q}{2mc}\right)\vec{s}$

anomalous magnetic moment : $a \equiv \frac{g-2}{2}$



Standard model can predict g with ultra high precision

$$g_\mu = 2.002331836408(718)$$

The Standard Model prediction according to Phys.Rev. D97 (2018) 114025

$g = 2$ from Dirac equation (point like, 1/2 spin particle) but $g \neq 2$ due to quantum-loop effects (vacuum polarization)

Useful in searching for new particles and/or interactions and experiment has reached the sensitivity to see such effects $\cdots$

Comparison Theory and Experience (example) $a_\mu^{SM} - a_\mu^{Exp.}$

Extract from Maurice Benayoun (Lpnhe/Paris) from Second Plenary Workshop of the Muon g-2 Theory Initiative (18-22 June 2018)

a_μ from BHLS2 Fits (update I)

HLS channels :

FSI updated

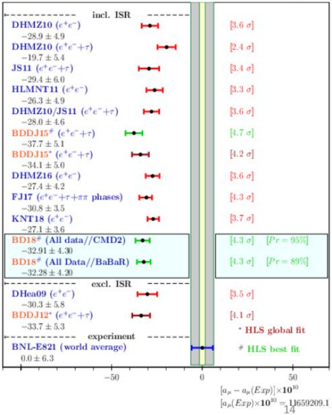
BHLS

Non HLS channels :

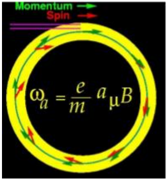
HVP update from FJ

• + ADD. SYST.

BHLS2

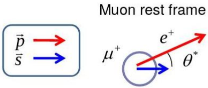


Sign of New Physics ? ⇒ very exciting !
Statistical fluctuation ? ⇒ redo a measurement !
Systematic error issue ? ⇒ g-2/EDM at J-PARC (very different systematic errors)
. . .



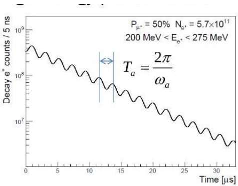
In uniform magnetic field, muon spin rotates ahead of momentum due to $g - 2 \neq 0$

$\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$



High energy positrons are larger due to larger phase space.
Positrons tends to be emitted in the muon spin direction.

High energy positron Time Spectrum



$$N(t) = N_0 \exp\left(-\frac{t}{\gamma\tau}\right)\left[1 - \cos\left(\omega_a t + \Phi\right)\right]$$

General form of spin precession vector :

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

BNL E821 - FNAL E989 approaches
$\gamma = 30$ $(P = 3\mathrm{GeV/c})$

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

J-PARC E34 approach
$E = 0$ at any γ

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$

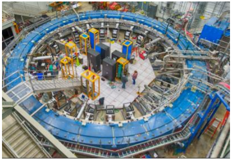
FNAL E989 : Analysis effort on-going for the first publication scheduled next year

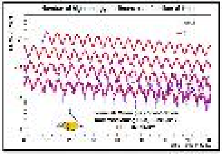
Commissioning Run concluded in Feb 2018

- Phase 1 (Summer 2017)
- Phase 2 (Fall 2017 to Spring 2018)

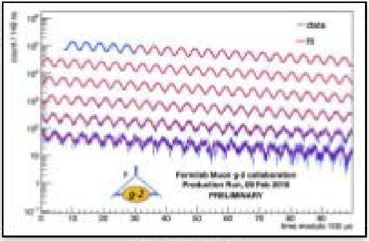
storage per bunch: 400x
storage per second: $10^?$x

Jun 2017





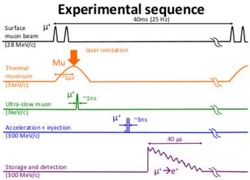
Jun 2017



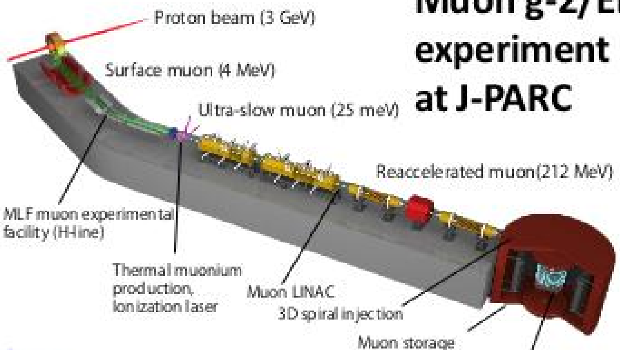
Feb 2018

Courtesy of Kim Siang Khaw

g-2/EDM at J-PARC The Collaboration : 99 "current members" from 41 institutions, 7 countries signed up for the collaboration bylaws (2017)



Muon g-2/EDM experiment at J-PARC



Features:

- Low emittance muon beam (1/1000)
- No strong focusing (1/1000) & good injection eff. (x10)
- Compact storage ring (1/20)
- Tracking detector with large acceptance
- Completely different from BNL/FNAL method

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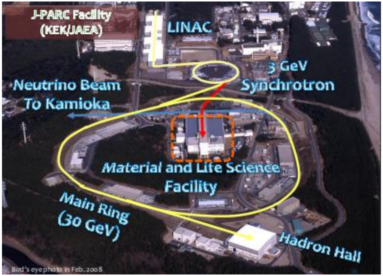
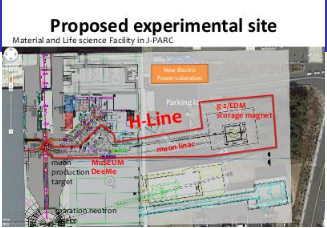
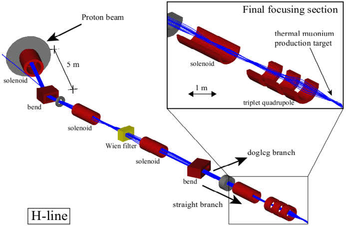
g-2/EDM at J-PARC: the H-line





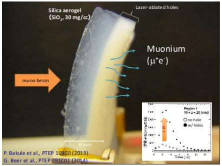


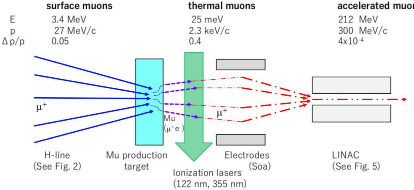
A 3 GeV primary proton beam with 1 MW beam power from the Rapid Cycle Synchrotron hits a 2 cm thick graphite target to provide pulsed muon beams. The experiment uses a surface muon beam. Surface muons are nearly 100 % polarized positive muons from pions stopped at and near the target surface. The H-line extracts muon beams.

g-2/EDM at J-PARC : Thermal muonium production - μ^+ production - μ^+ acceleration (linac) - μ^+ spiral injection and storage

μ^+ are slow down and thermalized in silica aerogel. Most of the muons form muonium atoms ($\mu^+ e^-$).

Muonium formed will diffuse to the surface of the slab and escape to vacuum with thermal energy. Intense laser beams strip the electron from muonium. The maximum polarization is 50 %.

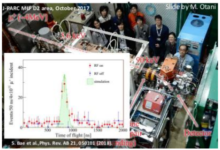




μ^+ are accelerated to a momentum of 300 MeV/c in a sufficiently short time compared with the μ lifetime. Another essential requirement for the acceleration is the suppression of transverse emittance growth.

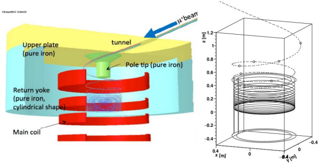
A new method to inject the muon beam !

Muon RF acceleration for the first

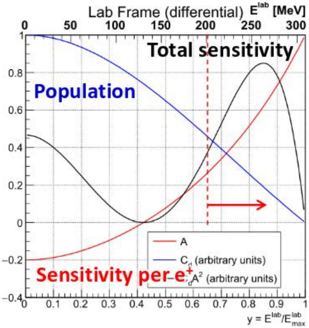


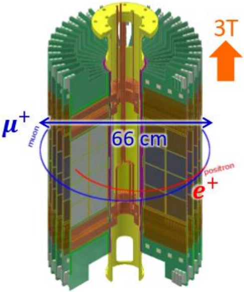
3D spiral injection + kicker

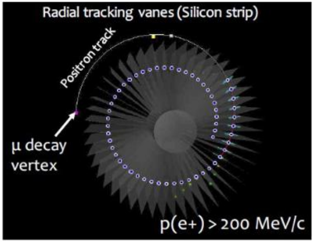
(J-PARC E34)



- Target particles : positrons from muon decay in 3T solenoidal B-field
  - Muon beam momentum : 300 MeV/c
  - The positron with higher momentum has better sensitivity on the muon g-2.
- Silicon strip detectors are radially placed to efficiently detect circular tracks.

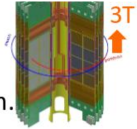




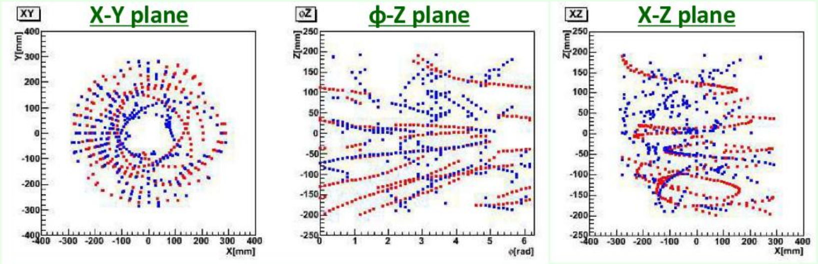


Muon Beam

- 40,000 muons/spill with 25 Hz
- About 30 muon decays per initial 5 ns
  - Four or five signal positron tracks (E > 200 MeV) among them.



15 Signal (E_{e+} > 200 MeV)
27 Bkg. (E_{e+} < 200 MeV)

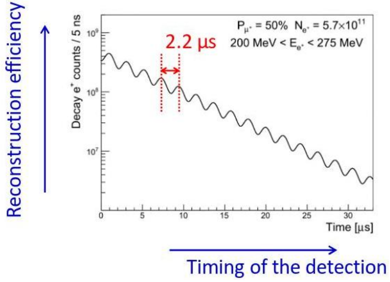


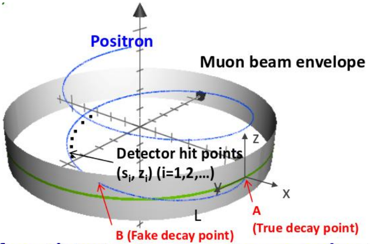
Key Issues for muon g-2 Measurement

For precise measurement of muon g-2, we need to determine:

1. **Precession frequency**
   - The decay positron rate changes by two orders of magnitude.

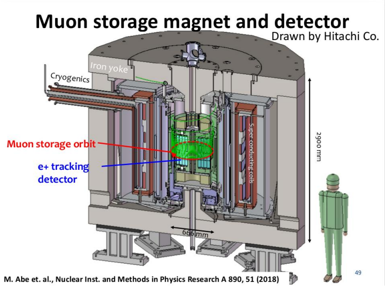
→ **Stable detection efficiency of the positron without timing bias (immune to "Early-to-Late Effect")**



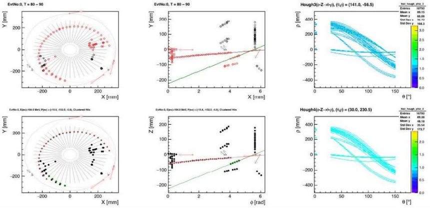


2. **Magnetic field felt by muon**
   - **No contamination of EM field from detector to muon storage region.**
     - Zero E-field (≪ 10^{-2} V/cm) at muon storage area
     - Not spoil the precision B-field (< 0.1 ppm) at muon storage area.

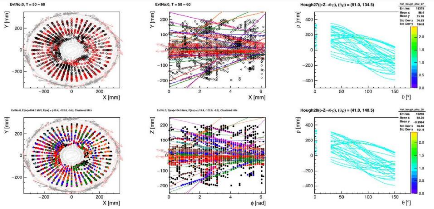
Track Finding : hough transform



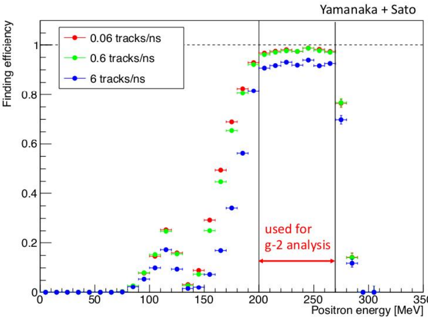
Track finding at low rate (0.6 track/ns)



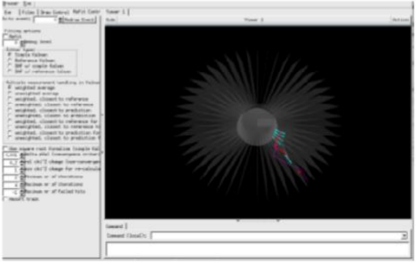
Track finding at high rate (6 track/ns)



Reconstruction efficiency



GENFIT offers many track fitting algorithm. Ideal choice for smaller collaborations which lack the manpower to develop dedicated track fitting package.
We input the silicon tracker geometry and a simulated positron event in GENFIT for track fitting.



(a) GENFIT GUI

(b) Typical fitted positron event

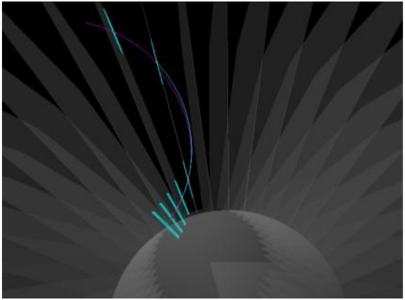
GENFIT development for very low momentum curler tracks

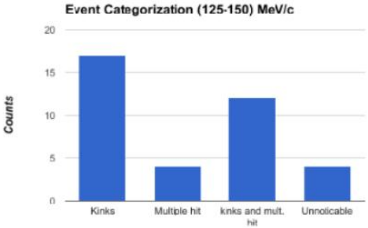
Track Fitting in the positron detector with GENFIT Shobhit Gupta , Wilfrid da Silva , Tsutomu Mibe (technical E34-NOTE-0033)

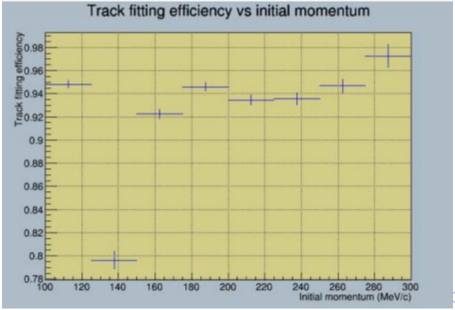
Low momentum regime e^+ are tangent to the vane, leading to multiple hits on the same vane. $\Longrightarrow$ Extrapolation method in GENFIT have been modify in order to take multiple

GENFIT can fit a positron track with two hits in the same vane now.

$\Downarrow$







Angular Velocity Vector Tilt

There is also a contribution of the magnetic dipole moment, the combined angular velocity vector with respect to the momentum direction is

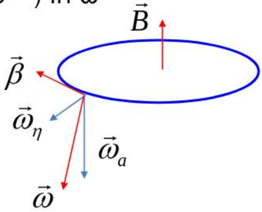
$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_\eta = -a\frac{q}{m}\vec{B} - \eta\frac{q}{2m}\left(\vec{\beta}\times\vec{B}\right)$$

– ω_η/ω_a (with $d_\mu = 10^{-21}$ e·cm) is about 10^{-5}

→ Too small to see a ω_η contribution ($\sim 10^{-10}$) in ω

→ But the tilt of angular velocity vector is visible ($\sim 10^{-5}$ rad)

$$\tan\delta = \frac{\omega_\eta}{\omega_a} = \frac{\eta\beta}{2a}$$



Thus, the number of up/down-going positrons can be written by

$$N_{\pm}(t) = \frac{N_0}{2}\exp\left(-\frac{t}{\gamma\tau}\right)\left[1 + A\cos(\omega t + \phi) \pm A_{\mathrm{EDM}}\sin(\omega t + \phi)\right]$$

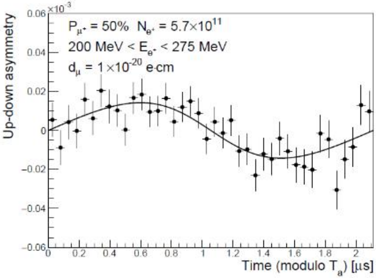
and the up-down asymmetry is obtained as

$$A_{ud}(t) = \frac{N_+(t) - N_-(t)}{N_+(t) + N_-(t)} = \frac{A_{\mathrm{EDM}}\sin(\omega t + \phi)}{1 + A\cos(\omega t + \phi)}$$

- ω, φ, A are already obtained by ω_a measurement.
- Only the remaining parameter is A_{EDM} and it is related with EDM by

$$A_{\mathrm{EDM}} = \frac{2A'}{\pi}\sin\delta \approx \frac{A'\beta\eta}{\pi a}$$

- *A'* is an analyzing power for EDM



Summary of statistics and uncertainties

	Estimation
Total number of muons in the storage magnet	5.2×10^{12}
Total number of reconstructed e^+ in the energy window [200,275 MeV]	5.7×10^{11}
Effective analyzing power	0.42
Statistical uncertainty on ω_a [ppb]	450
Uncertainties on a_μ [ppb]	450 (stat.)
	< 70 (syst.)
Uncertainties on EDM [10^{-21} e·cm]	1.5 (stat.)
	0.36 (syst.)

	BNL-E821	Fermilab-E989	This Experiment
Muon momentum	3.09 GeV/c		0.3 GeV/c
Lorentz γ	29.3		3
Polarization	100%		50%
Storage field	$B = 1.45$ T		$B = 3.0$ T
Focusing field	Electric quadrupole		Very weak magnetic
Cyclotron period	149 ns		7.4 ns
Spin precession period	4.37 μs		2.11 μs
Number of detected e^+	5.0×10^9	1.8×10^{11}	5.7×10^{11}
Number of detected e^-	3.6×10^9	–	–
Stat. precision (a_μ)	460 ppb	140 ppb	450 ppb
Stat. precision (EDM)	0.2×10^{-19} $e \cdot$ cm	10^{-21} $e \cdot$ cm	10^{-21} $e \cdot$ cm

Institute of Particle and Nuclear Studies (IPNS) gives g-2/EDM stage-2 approval

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18. 11 22

Dear Dr. T. Mibe,

This comes in response to your proposal E34 titled *"An Experimental Proposal on a New Measurement of the Muon Anomalous Magnetic Moment g-2 and Electric Dipole Moment at J-PARC"* presented to the 26th meeting of the J-PARC Program Advisory Committee for the Nuclear and Particle Physics Experiments at the J-PARC Main Ring, held on July 18-20, 2018. The committee evaluated the scientific merits and technical feasibility of this proposal and provided the following statement.

E34 (g-2/EDM)
The E34 (g-2) experiment aims to measure the anomalous magnetic moment (g-2) and electric dipole moment of the muon.

E34 reported progress in many areas. The g-2 theory initiative has reported progress on improving the hadronic vacuum polarization and light-by-light scattering contributions and expects to produce a white paper in early 2019. The improved collaboration organization was shown and is reported to be functioning. The building for the necessary power for g-2 is being constructed in FY2018. The various steps in the acceleration of the bright muon beam have been demonstrated to 90 keV (with an article in the CERN Courier and with several papers published including three in 2018). The next step is to demonstrate acceleration to 1 MeV. The collaboration plans to publish a TDR summary on the experiment design.

The updated TDR and responses to the recommendations by the PAC and Focused Review Committee (FRC) were reviewed by the FRC. A report from the FRC has been given to the PAC recommending stage-2 approval. The PAC suggests that g-2 work with Lab management to refine the cost estimate and schedule.

Following the recommendation of the FRC, recognizing the tremendous progress by the g-2 collaboration and plans for addressing remaining issues the PAC recommends stage-2 approval.

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Based upon this advice from the PAC, we are granting by this letter stage-2 approval for this experiment and will promote efforts to obtain the budget for facility construction, subject to the priority in KEK PIP. We will provide a minimum of support for R&D after hearing the group's R&D plan before the start of full funding. Please note that if the budget condition is not improved for a long time, we may need to ask the PAC to re-evaluate the project including an option of cancellation.

Sincerely,

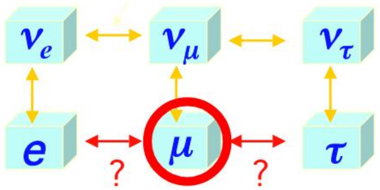
Katsuo Tokushuku
Director
Institute of Particle and Nuclear Physics
KEK

Naohito Saito
Director
J-PARC Center

cc:
PAC members: I. Adachi, N. Aoi, M. Blanke, D. Harris, Y. Itoh, S. Kettell, R. Kitano, M. Kuze, F. Le Diberder, A. Ohnishi, J. Pochodzalla, H.Tamura, A. W. Thomas, R. Yoshida (Chairperson), N. Xu

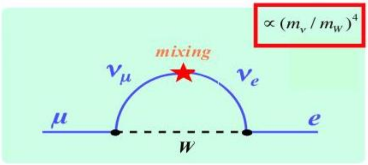
Lepton Flavor Violation (LFV) of Charged Leptons

Neutrino Mixing
(confirmed)



Charged Lepton Mixing
(not observed)

Contribution to lepton flavor violation of charged leptons from Neutrinos



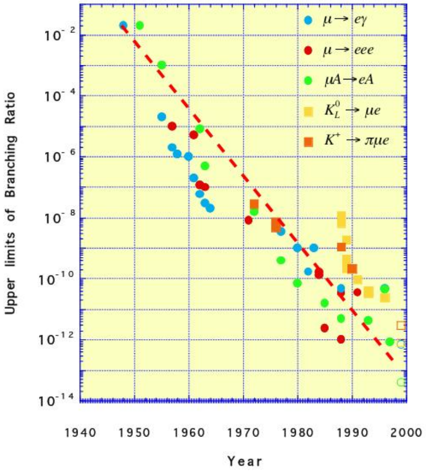
Very Small (10^{-54})

Sensitive to new Physics beyong the Standard Model

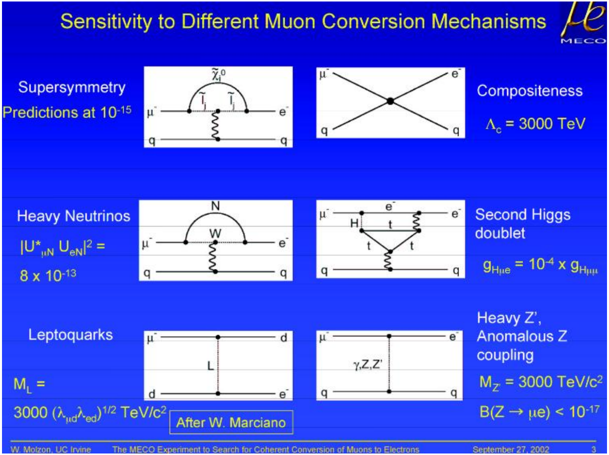
Observation of CLFV would indicate a clear signal of physics beyond the SM.

A long history of the LFV search, which started from the experiment with cosmic rays by Pontecorvo et al. in 1947.

Since then, the upper limits have been improved by two orders of magnitude per decade with muons that are created by accelerators



Various Models Predict CLFV ......



Such a sensitivity could be translated into probing many new physics construction up to $\mathcal{O}(10^4)$ TeV energy scales, which would go beyond the level that can be reached directly by collider experiments. The search for CLFV $\mu \to e$ conversion is thus highly complementary to BSM searches at the LHC.

List of Lepton Flavor Violating Processes with Muons

The neutrinoless muon to electron conversion process has a sensitivity to BSM physics from both dipole (loop) and non-dipole interactions.
This is in contrast to the $\mu \to e\gamma$ process which is only sensitive to dipole interactions and
$\frac{B(\mu N \to eN)}{B(\mu \to e\gamma)} \sim \frac{1}{100}$

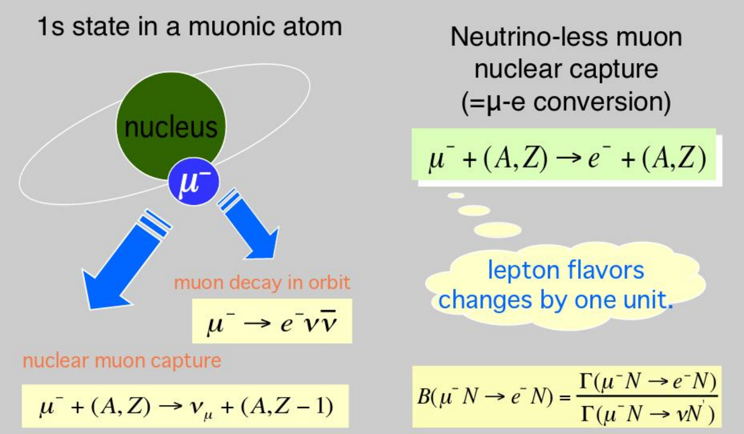
ΔL=1

- $\mu^+ \to e^+\gamma$
- $\mu^+ \to e^+e^+e^-$
- $\mu^- + N(A,Z) \to e^- + N(A,Z)$
- $\mu^- + N(A,Z) \to e^+ + N(A,Z-2)$

ΔL=2

- $\mu^+e^- \to \mu^-e^+$
- $\mu^- + N(A,Z) \to \mu^+ + N(A,Z-2)$
- $\nu_\mu + N(A,Z) \to \mu^+ + N(A,Z-1)$
- $\nu_\mu + N(A,Z) \to \mu^+\mu^+\mu^- + N(A,Z-1)$

One of the most prominent muon CLFV processes is coherent neutrinoless conversion of muons to electrons conversion.



$\mu - e$ Conversion Signal and Backgrounds

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

- Signal
  - single mono-energetic electron

$$m_\mu - B_\mu \sim 105 MeV$$

  - coherent process (the same initial and final nucleus)

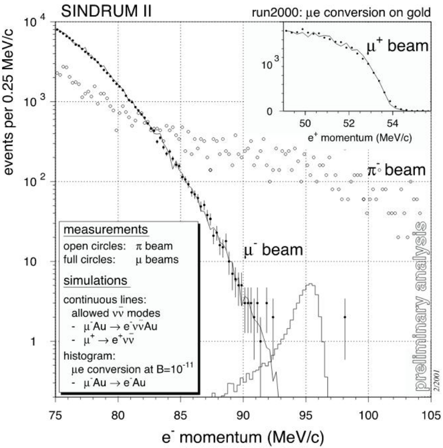
$$\propto Z^5$$

- Backgrounds
  - Muon decay in orbit
    - Endpoint comes to the signal region $\propto (\Delta E)^5$
  - Radiative muon capture
  - Radiative pion capture
    - with asymmetric photon conversion
  - Electrons from muon decays in flight
  - Cosmic rays
  - and many others

Present Experimental Status of searches for $\mu - e$ conversion

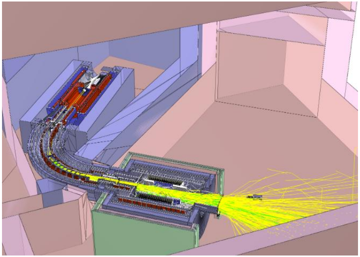
The latest search for $\mu - e$ conversion was performed by the SINDRUM II collaboration at PSI.

Year	Location	Process	upper limit
1972	SREL	$\mu^- + \mathrm{Cu} \to e^- + \mathrm{Cu}$	$< 1.6 \times 10^{-8}$
1982	SIN	$\mu^- + {}^{32}\mathrm{S} \to e^- + {}^{32}\mathrm{S}$	$< 7 \times 10^{-11}$
1985	TRIUMF	$\mu^- + \mathrm{Ti} \to e^- + \mathrm{Ti}$	$< 1.6 \times 10^{-11}$
1988	TRIUMF	$\mu^- + \mathrm{Ti} \to e^- + \mathrm{Ti}$	$< 4.6 \times 10^{-12}$
1988	TRIUMF	$\mu^- + \mathrm{Pb} \to e^- + \mathrm{Pb}$	$< 4.9 \times 10^{-10}$
1993	PSI	$\mu^- + \mathrm{Ti} \to e^- + \mathrm{Ti}$	$< 4.3 \times 10^{-12}$
1996	PSI	$\mu^- + \mathrm{Pb} \to e^- + \mathrm{Pb}$	$< 4.6 \times 10^{-11}$
1998*	PSI	$\mu^- + \mathrm{Ti} \to e^- + \mathrm{Ti}$	$< 6.1 \times 10^{-13}$
2006	PSI	$\mu^- + \mathrm{Au} \to e^- + \mathrm{Au}$	$< 7 \times 10^{-13}$



The COMET experiment : a staged approach

First stage - Single Event Sensitivity (SES) : 3.0×10^{-15} (Phase-I)
Second stage - SES : 2.6×10^{-17} (Phase-II)



Phase-I layout of the COMET experiment, showing the first 90^o bend of the muon transport beam line. The detector will be placed at the end of the muon transport section. (under construction)

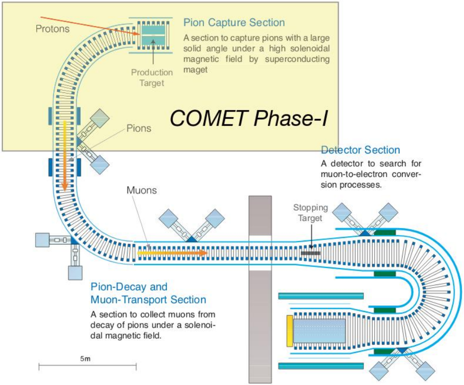


Figure 2.1: *Schematic layout of COMET (Phase-II) and COMET Phase-I (not in scale),*

ICEDUST COMET Simulations (for more see Ewen Gillies seminar)
⇒ require a lot of CPU and Storage
⇒ Mostly Official COMET simulation hase been done at the French computing center CC-IN2P3 (see next next slides)

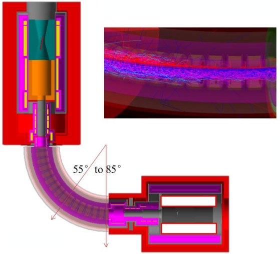


Figure 8.5: *Schematic layout of muon beam collimators placed inside the muon transport solenoid from 55° to the end, and event displays (top right) with the collimators in place in the muon transport solenoids. Tracks in blue are μ^-, those in red are μ^+.*

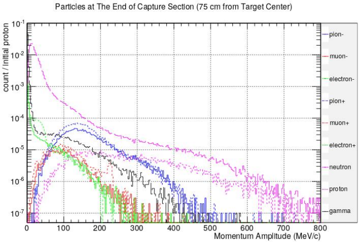
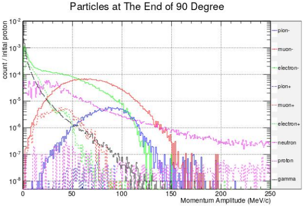
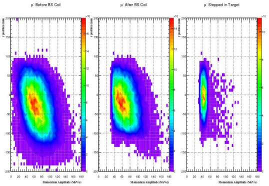


Figure 8.3: *Momentum distribution of various beam particles at the end of the pion capture solenoid section, moving to the muon transport section. For the hadron production, GEANT_QGSP_BERT was used.*





e^- Track Fitting using GENFIT (can benefit of g-2 tracking synergy)

Fitted Momentum minus 105.0 MeV Distribution (for the $\mu - e$ conversion signal)

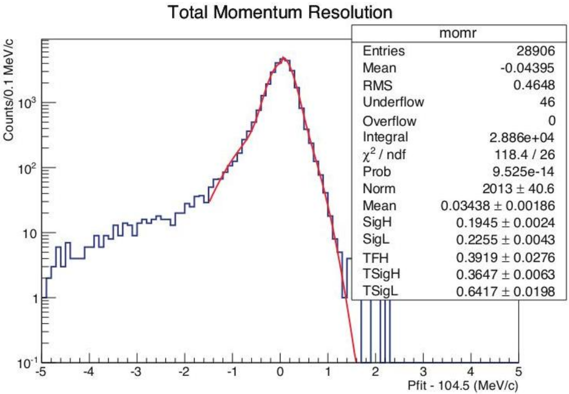
Leading track fitting Team :
Osaka University and IHEP ↘

Lower momentum side tail due to :
energy loss in the muon stopping target

Higher momentum side tail due to :
energy straggling in the muon stopping target and the CDC inner wall

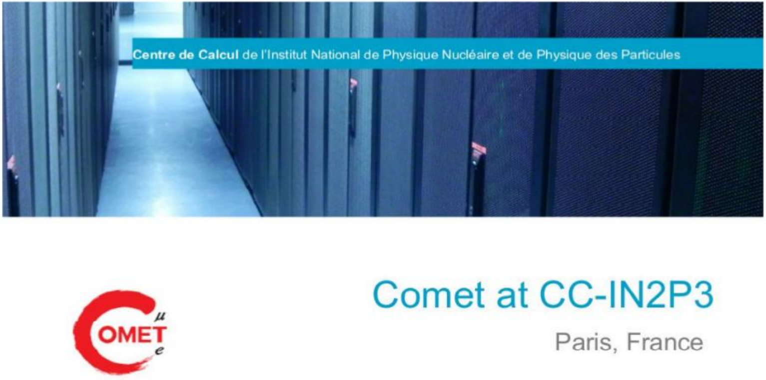
Momentum resolution is important :
for eliminate intrinsic backgrounds from regular muon decays (in particular on the higher momentum side)

Multiple turn tracks are treated initially as a set of a few single turn tracks, and then they are combined to form one multiple turn track. To fit all hits same GENFIT developments in extrapolation method like g-2/EDM at J-PARC are under studied (in FCPPL)



Core	σ of high-momentum half-Gaussian (SigH)	195 keV/c
	σ of low-momentum half-Gaussian (SigL)	226 keV/c
Fraction in tail distribution (TFH)		39%
Tail	σ of high-momentum half-Gaussian (TSigH)	365 keV/c
	σ of low-momentum half-Gaussian (TSigL)	642 keV/c

National Institute of Nuclear and Particle Physics Computing Center (CC-IN2P3)



CC-IN2P3 some facts and figures

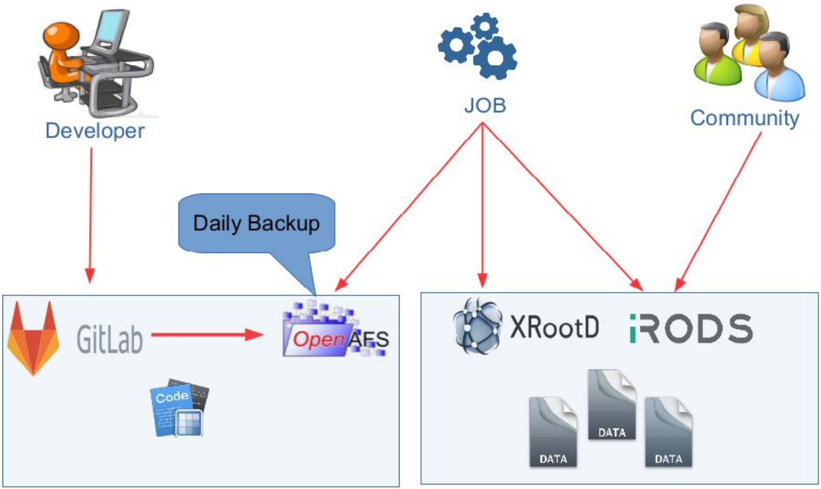
- CC-IN2P3 provides:
  - Storage and computing resources:
    - Local, grid and cloud access to the resources.
  - Database services.
  - Hosting web sites, mail services.
- 2100 local active users (even more with grid users):
  - including 600 foreign users.
- ~ 140 active groups (lab, experiment, project).
- ~ 36000 cores batch system (hyperthreading activated)
- ~ 50 PBs of data stored on disk and tapes.

Data Management

Several technologies to response different needs:

- IRODS: Main repository for share and access data
- XROOTD: Disk cache pool for local massive parallel access (cluster production)
- GitLab: Source code version control
- AFS: Code distribution (cluster production)
- PBS: local group space (backuped)
- SPS: local group space (temporary)

Massive production



iRODS

- Open source software
- Data discovery
- Work-flow automation
- Secure collaboration
- Data virtualization across platforms and locations
- Clients: web, desktop graphical, WebDav, icommands
- API: C/C++, Java, REST (http-based), R Client, Qt

Hosting and Collaborative Services

- Source code version control
- Collaborative tools for developing and sharing software (host, documentation, bug database)
- Website content and structure modifiable in collaborative and easy way (from web browser)
- Hosting web applications from different technologies

- Gitlab (Github clone)
- Forge
- Wiki
- Web hosting
  - Applications: php, java, python
  - Several technologies: Apache tomcat,

COMET Resources Utilisation

- See: Comet report (link)
- http://cctools.in2p3.fr/mrtguser/
- 140 MHS06 (~14 Mhours) for 2018

- Unix/AFS: groupe Comet ~50 accounts
- Irods: ~30 accounts
- GitLab: ~50 members, ~11 projects

Test the Apollonius method on signal + background event seems promissing but consuming computing time analysis ongoing in the framework of FCPPL agreement.

Apollonius's problem : construct circles that are tangent to three given circles in a plane

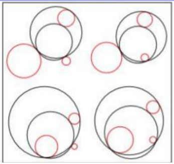
Greek Apollonius of Perga (200 BC)

Compass constructions by French François Viète (1600)

Algebraic solution (cyclographic model) :

$$(-x_1+x_s)^2+(-y_1+y_s)^2 = (r_s-r_1\ s_1)^2$$
$$(-x_2+x_s)^2+(-y_2+y_s)^2 = (r_s-r_2\ s_2)^2$$
$$(-x_3+x_s)^2+(-y_3+y_s)^2 = (r_s-r_3\ s_3)^2$$

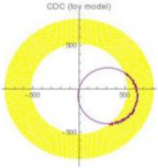
with $s_{1,2,3} = \pm 1$

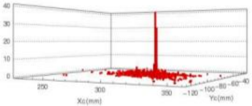


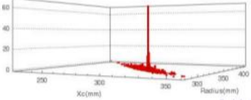
Build all Apollonius circles using all COMET Drift Chamber (CDC) drift distance hit triplets and vote ↘

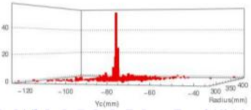
Pseudo code

1. Order hits by nearest distance (First hit with lowest x-coord.)
2. Take 3 hits not too near (here : distant of 16 cell size)
3. Compute the 8 Apollonius circles
4. Store Xc, Yc center and Radius of all Apollonius circle in 3D accumulator,
5. Redo with 3 new hits · · · until end.
6. Plot distribution results (left figure)



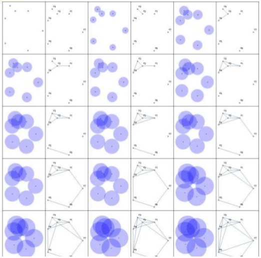


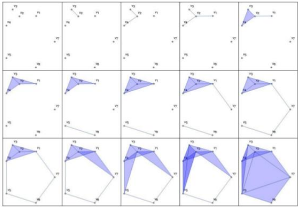




Paris : Track Finding Study using Persistent Homology (preliminary)

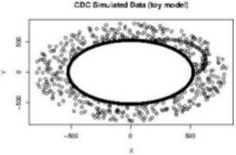
Vertices : replace data points by vertices
Edeges : link two vertices if their distance is lower than the ball diameter
Increase the ball diameter $\cdots$
To fill the loops :
Vietoris-Rips rules : fill the triangle
notion of peristence (see main loop) $\Rightarrow$

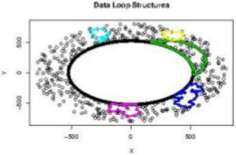


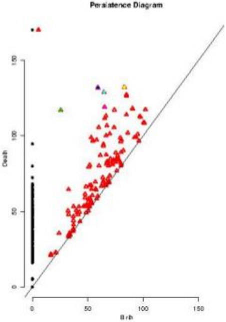


Build the Persistence Diagram and have a look on loops having the larger lifetime
Analysis ongoing in the framework of FCPPL agreement. $\searrow$

- PH : computing time ~ 30 s
- All finding loops are represented by a red or colored triangles in the Persistence Diagram (left figure).
- Points near the diagonal represent generally the background (dead radius $\sim$ birth radius)
- Finding loops with highest dead radius are schown and colored (yellow, green (track !), blue light, blue dark, $\cdots$
- The signal (green) seems still well separed from the background



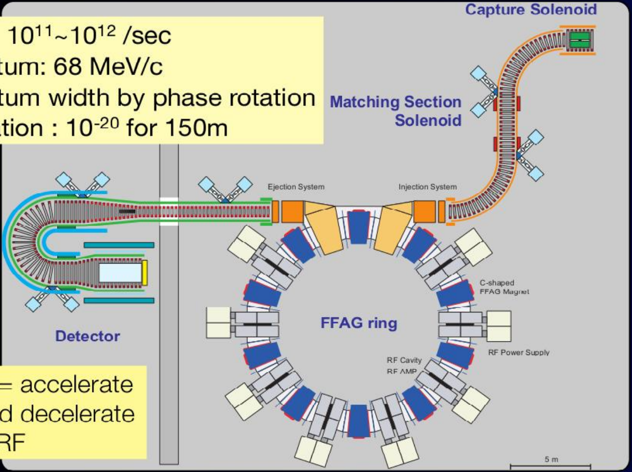




PRISM Muon Beam

PRISM=Phase Rotated
Intense Slow Muon source

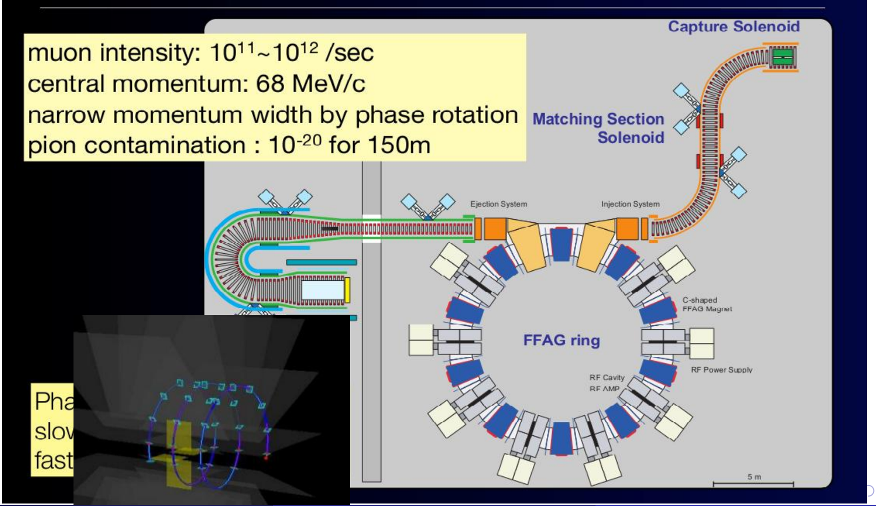
muon intensity: $10^{11} \sim 10^{12}$ /sec
central momentum: 68 MeV/c
narrow momentum width by phase rotation
pion contamination : 10^{-20} for 150m



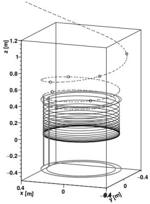
Phase rotation = accelerate
slow muons and decelerate
fast muons by RF

PARIS : "Muon Cylindric Converter" as a futur COMET PHASE X=3 ???

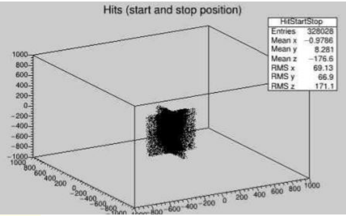
Explore the possibility of :
Silicon radial vanes for Stopping Target (yellow)
Silicon vane detector for the tracking of electrons (gray)



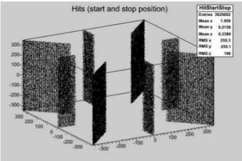
μ^- beam injection " à la g-2/EDM" (nominale trajectory)



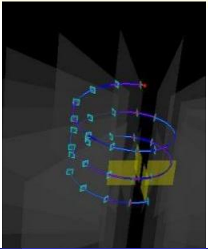
Distribution of entrance and stopping μ^- hits in 4 silicon radial stopping target vanes (in yellow $\Downarrow$)



Distribution of e^- hits in 8 silicon radial detector vanes (after the decay of the muon in the stopping target) (in gray $\Rightarrow$)



Fitted e^- trajectory with GENFIT



MCC : fitting e^- from μ^- conversion with GENFIT (study ongoing)

GENFIT modification currently underdevelopment

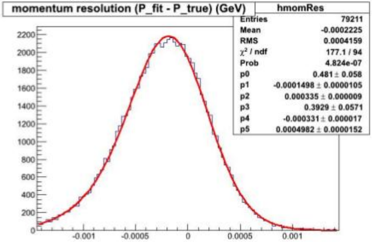
1. Total rewriting of the method giving the estimation track extrapolation length. Now no approximation of a linear trajectory of the particle is made. We now assumed that the trajectory is an helix given by a constant magnetic field whose value is taken at the starting point of the extrapolation.
2. Modification of Kalman Filter method in order to give the measurement points to the method which compute the estimation track extrapolation length.
3. Do the same for the DAF, Reference Kalman filter, $\cdots$

Some very preliminary results

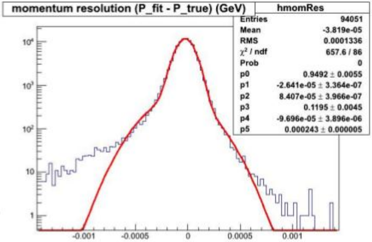
N_{vane}	thickness (μm)	$\varepsilon_{\text{fitting}}$	σ_1 (keV)	σ_2 (keV)	fraction$_1$
8	50	63%	85	243	89 %
8	300	52%	335	499	55%
16	50	84%	143	374	86%
16	300	72%	394	605	8%

$\Rightarrow$ Need more study on extrapolation (20% lost suspected ?)
$\Rightarrow$ Need more study on χ^2 by hit (10% lost suspected ?)
$\Rightarrow$ Study the track finding, test for other type of measurements $\cdot$

$N_{\text{vane}} = 8$, thickness $= 300\ \mu$m



$N_{\text{vane}} = 8$, thickness $= 50\ \mu$m



- g-2/EDM
- COMET
- CC-IN2P3
- LPNHE/Paris FCPPL-FJPPL
- . . .
- Thank You Very Much