Flash talk

E. Bottalico

Leverhulme Physics Retreat

17 Sept 2025

LEVERHULME TRUST

UNIVERSITY OF LIVERPOOL

About me

Before physics

About me

Before physics

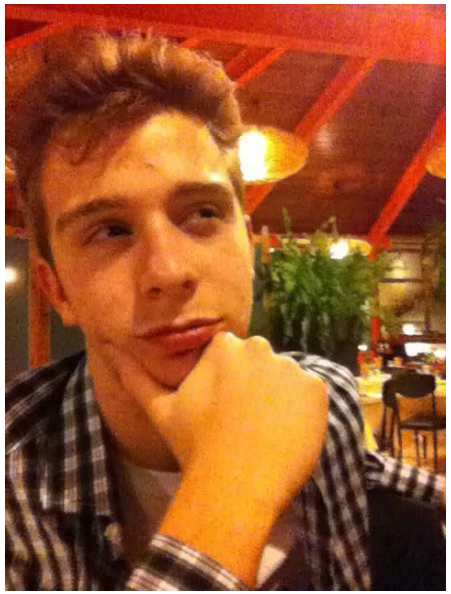
After physics

About me

LEVERHULME TRUST

Before physics

In between
Maybe physics didn't do a too bad job 😂



After physics

About me

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The Oliver Lodge, Oxford St,
Liverpool L69 7ZE

About me:

- Graduation in Physics (University of Pisa);
- Master in High Energy Particle Physics (University of Pisa);
- Ph.D title “Beam Dynamics corrections in the measurement of the anomalous precession frequency at the Muon $g-2$ experiment at Fermilab” (University of Pisa).

Past experiences:

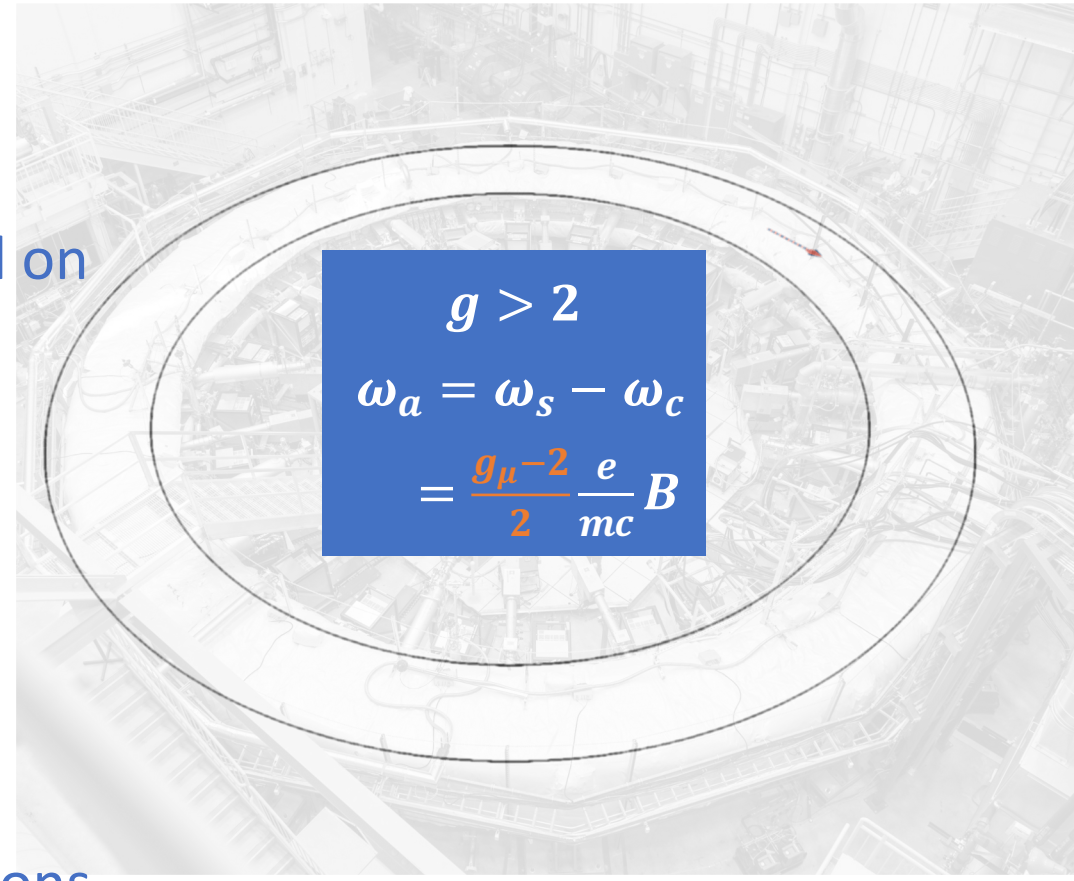
- Member of the EDI committee;
- Run Coordinator for Run-5 and Run-6 at the g-2 experiment;
- Convener of the Beam Dynamics corrections analysis during Run-2/3.

Hobbies:

- Play the guitar, read books, watch movies and eat (a lot🙂)

About research

- Most of my career has been spent working on the Muon g-2 experiment at Fermilab.
- I worked on several aspects:
  - Developing the **Long Term Gain correction**, based on a state-of-art laser system;
  - Investigating a **new systematic** that heavily **impacted Run-1 results**;
- **In the past 2 years:**
  - Studying the data-simulation agreement;
  - **Leading** the **analysis** of 2 beam dynamics corrections
  - **Analysis coordinator** of **beam dynamics analysis.**



About research

- The formula shows the R'_μ calculation to extract a_μ.
- The corrections applied to the measured anomalous precession frequency ω_a^m are necessary to get an unbiased a_μ result.

Beam dynamics corrections

$$R'_\mu \approx \frac{f_{clock}\omega_a^m\left(1 + C_e + C_p + C_{ml} + C_{pa} + C_{dd}\right)}{f_{calib} < \omega'_p(x,y,\phi) \times M(x,y,\phi) > \left(1 + B_k + B_q\right)}$$

- The total beam dynamics correction applied in **Run-456** is: **515 ppb** with a systematic of **42 ppb**

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My work

Beam dynamics corrections

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- The total beam dynamics correction applied in **Run-456** is: **515 ppb** with a systematic of **42 ppb**

About research - C_e

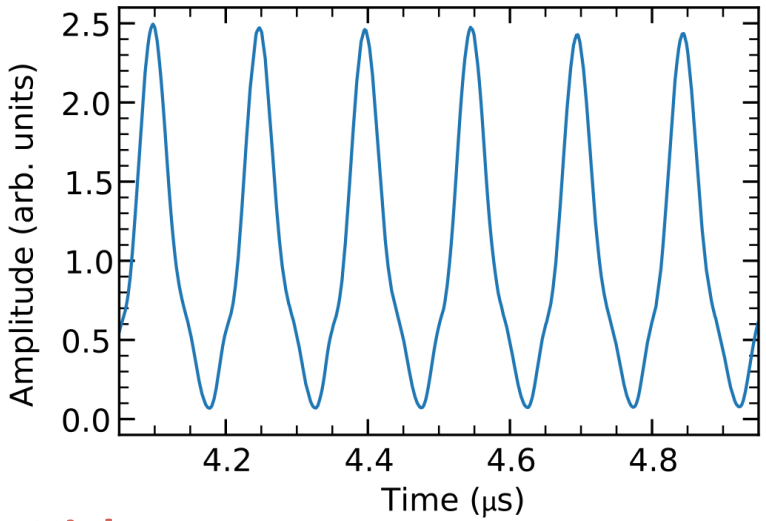
- The formula represents the anomalous precession frequency:

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

- In the g-2 experiment we choose the energy of the muon to satisfy the relation: $\gamma = \sqrt{1 + \frac{1}{a_\mu}} \approx 29.3$ equivalent to a $\boldsymbol{p}_{\boldsymbol{\mu}} = \mathbf{3.094}$ **Gev/c**

- However, not all the muons are at the magic momentum, so some residual $\vec{E}$ affects the muon beam.

About research - C_e



Higher momentum muons:

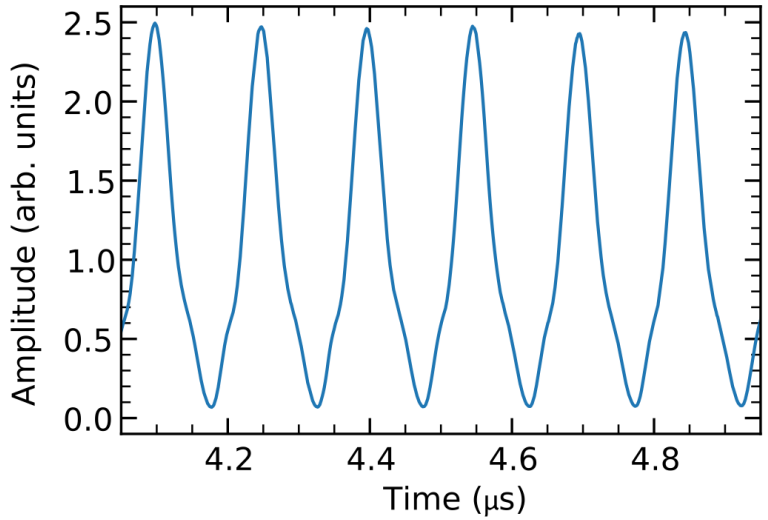
- stored at **larger radii**
- take **longer** to go around

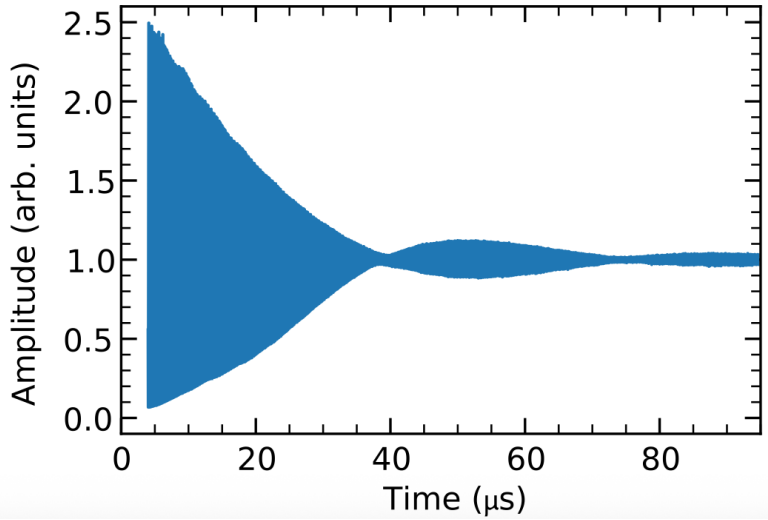
Lower momentum muons:

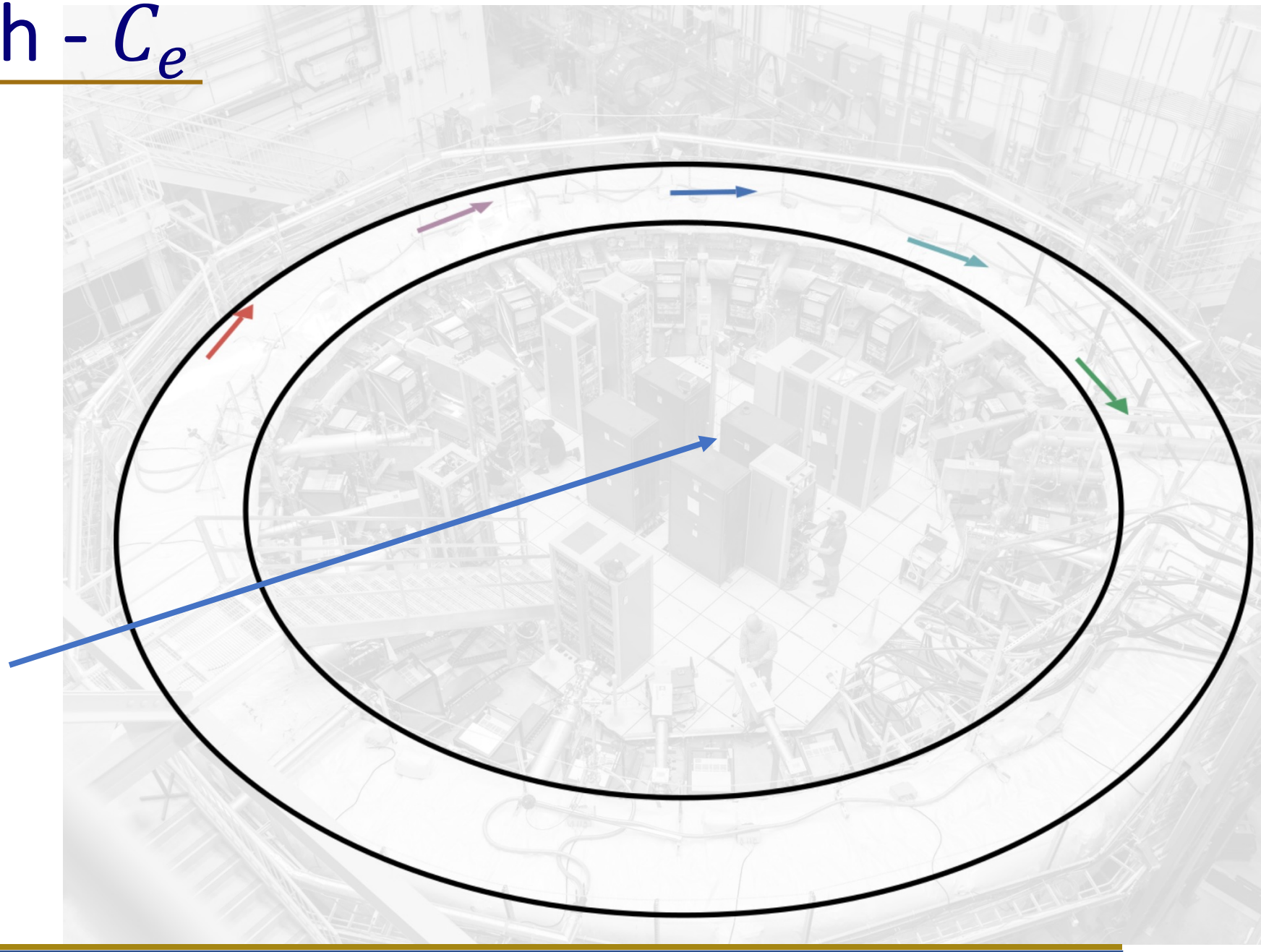
- stored at **smaller radii**
- take **shorter** to go around

Dephasing and **radial position** used to extract the stored momentum spectrum

About research - C_e







About research - C_e

- In E821 and Run-1 we used the CERN method to extract the electric field correction, building the χ^2 from the Fast rotation signal:

Propagator function

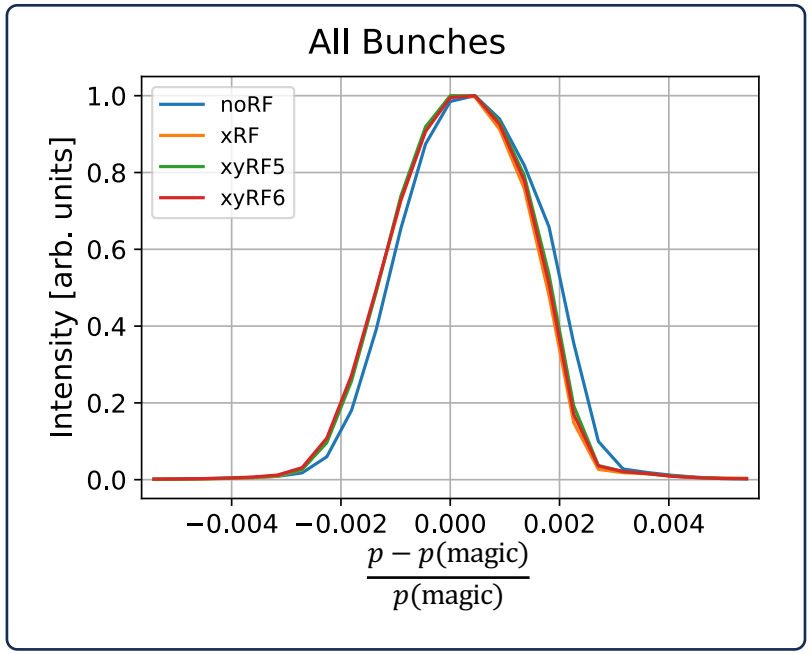
Injection time

Time Momentum Correlation

$$\chi^2 = \sum_j \frac{\left(S_j - \sum_{ik} \beta_{ijk} \Sigma_m R_i T_k \epsilon_{ikm}\right)}{\sigma_j}$$

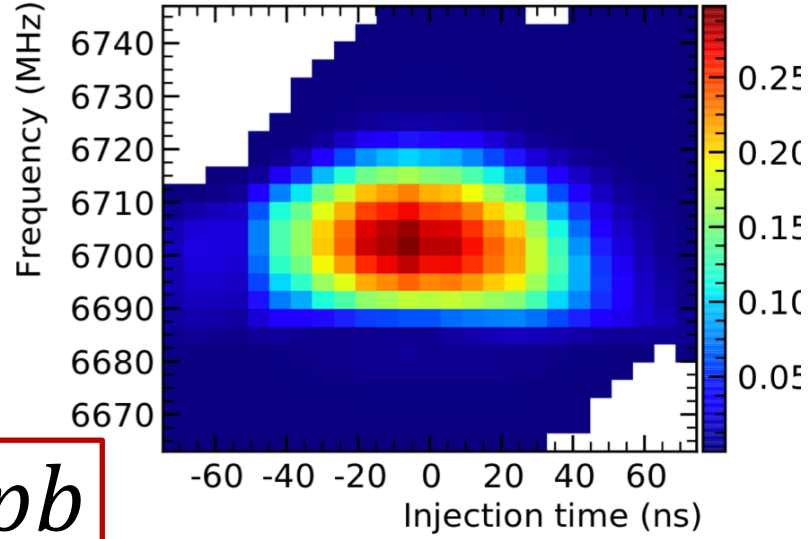
Fast rotation signal

Equilibrium radius



Vertical projection

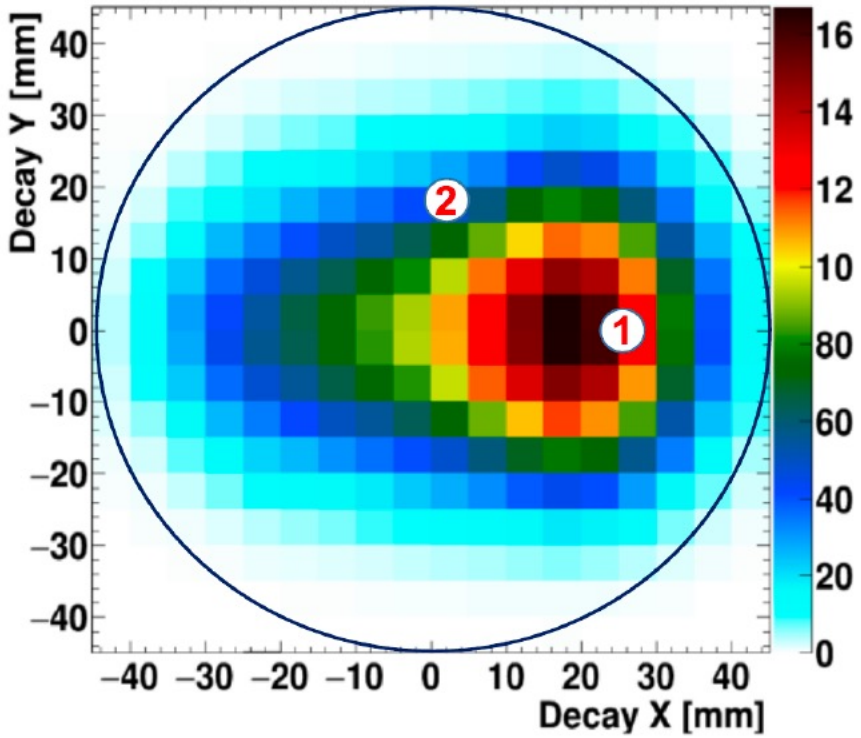
$$C_E = \frac{2n\beta_0^2}{1-n}\langle \delta^2 \rangle$$



$$C_e = 347(27)\ ppb$$

About research - C_{pa}

- The measured *g-2* phase of the muon is decay vertex position dependent.
- It is obtained as weighted average of the phases measured by each (x,y) pair position.



$$N_2(t) = N_{02} e^{-t/\tau} \left[1 + A_2 \cos(\omega_a t + \phi_2)\right]$$

$$N_1(t) = N_{01} e^{-t/\tau} \left[1 + A_1 \cos(\omega_a t + \phi_1)\right]$$

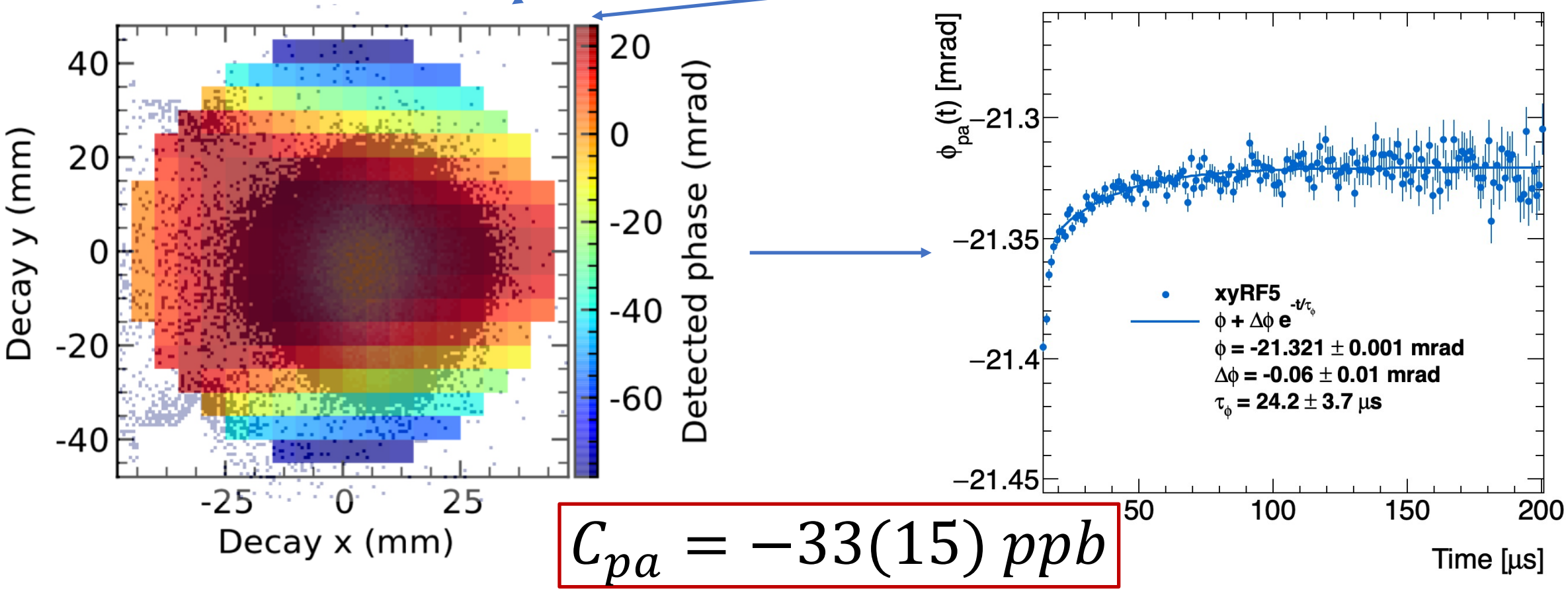
$$N(t) = N_1(t) + N_2(t) = N_\Sigma e^{-t/\tau} \left[1 + A_\Sigma \cos(\omega_a t + \phi_\Sigma)\right]$$

$$\phi_\Sigma = \arctan \frac{N_{01} A_1 \sin(\phi_1) + N_{02} A_2 \sin(\phi_2)}{N_{01} A_1 \cos(\phi_1) + N_{02} A_2 \cos(\phi_2)}$$

About research - C_{pa}

Simulation

$$\varphi_0^{c_k}(t) = \arctan \frac{\sum_{ij} M_{T,k}(x_i, y_j, t) \cdot \varepsilon_{c,k}(x_i, y_j) \cdot A_k(x_i, y_j) \cdot \sin(\varphi_{0,k}(x_i, y_j))}{\sum_{ij} M_{T,k}(x_i, y_j, t) \cdot \varepsilon_{c,k}(x_i, y_j) \cdot A_k(x_i, y_j) \cdot \cos(\varphi_{0,k}(x_i, y_j))}$$

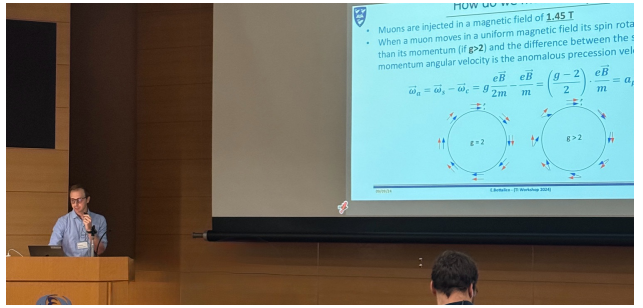


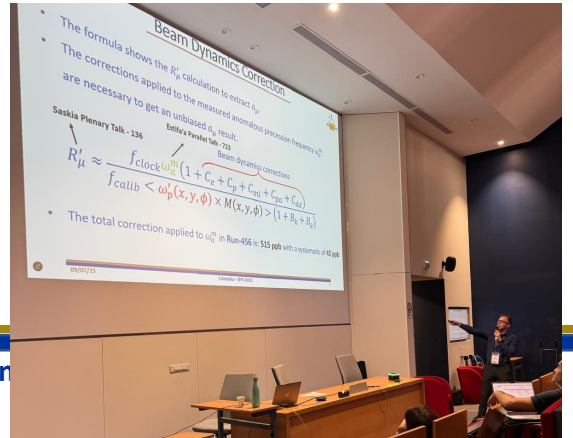
$$C_{pa} = -33(15)\ ppb$$

About research

- I had also the possibility to participate to many conferences:

  - Beauty 2023 – Clermont-Ferrand (France);
  - EINN 2023 – Paphos (Cyprus);
  - Theory Initiative 2024 – Tsukuba (Japan);
  - Shanghai Workshop 2025 – Shanghai (China);
  - EPS 2025 – Marseille (France);





About research

…But also to explore the world!

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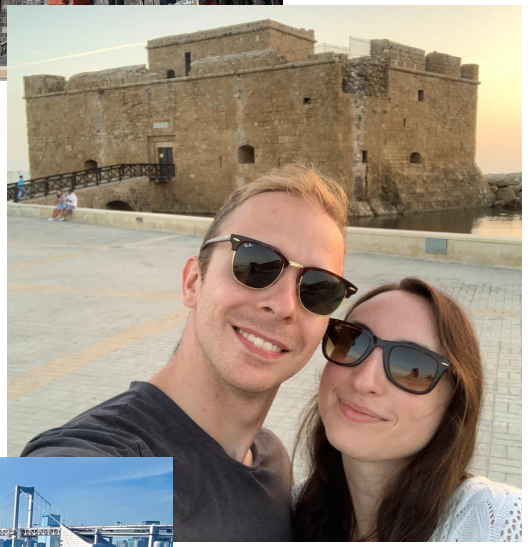

About research

…And delicious food!!!

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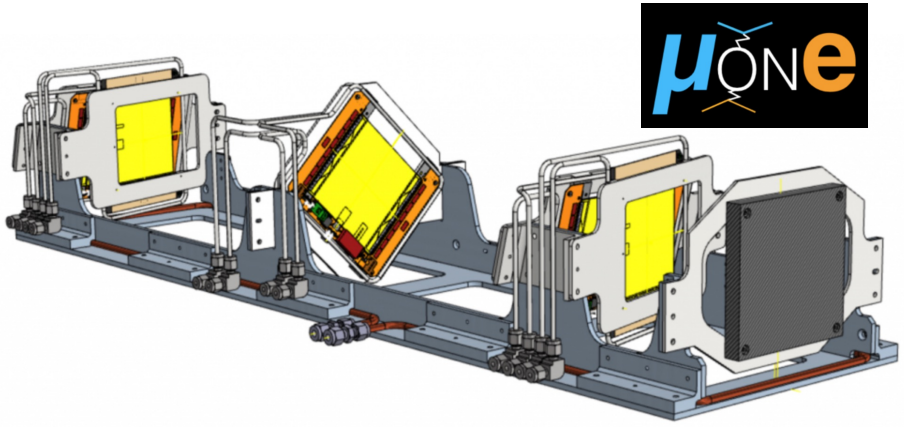
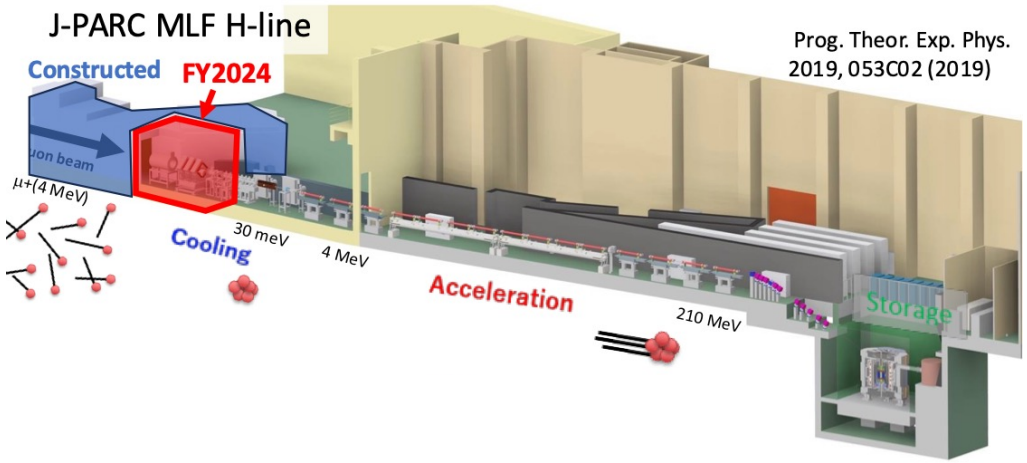
Look at the future!

- Looking at the future, nice projects are brewing:
  - The MUonE experiment who aims to measure the a_μ^{HLO} a 0.3% stat precision.



  - The Muon g-2/EDM J-PARC experiment who aims to measure the g-2 at similar precision to Fermilab experiment.



Thanks a lot!