A proposal for measuring

$$\mu + e \longrightarrow \mu + e$$

scattering

Enquiry with COMPASS Collaboration….

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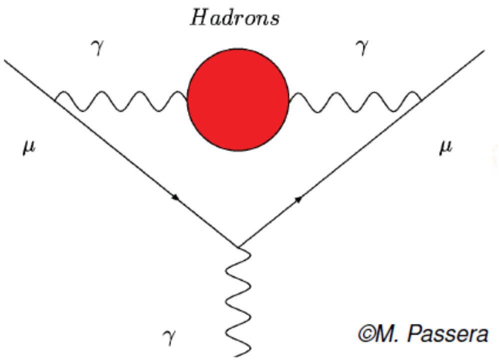
Outline

- **Physics motivations**
- **Tools to perform the measurement**
  (requirements on beam, detector)
- **Could COMPASS tell us information on elastic events?**

Physics motivations

To measure the Hadronic Leading Order contribution (HLO) to the muon g-2 in the space-like region



Proposed by:

G. Abbiendi, C.M. Carloni Calame, U. Marconi, C. Matteuzzi, G.Montagna, O. Nicrosini, M. Passera, F. Piccinini, R. Tenchini, L.Trentadue, G.Venanzoni

Reference:

G. Abbiendi et al., Eur. Phys. J. C (2017) 77:139. doi :10.1140/epjc/s10052-017-4633-z.

Physics motivations

The muon g-2 is measured with high precision:

Today: $a_\mu^{\exp} = (11659208.9 \pm 5.4_{\rm stat} \pm 3.3_{\rm sys}) \times 10^{-10}$ [0.5 ppm] BNL E821

And it shows a long standing deviation from theStandard Model prediction:

$$\Rightarrow \quad a_\mu^{\exp} - a_\mu^{\rm SM} = (27.4 \pm 8.0) \cdot 10^{-10} \quad [3.4\sigma]$$

Both Fermilab and J-PARC g-2 experiments will lower the experimental error from 0.5 ppm to ≈ 0.14 ppm in few years

Need therefore to lower the theoretical uncertainty in order to have a more precise SM prediction ⇒ *more theoretical work is necessary (rad corr, lattice,..)*

The largest contribution to the theoretical uncertainty comes from the term $\Delta\alpha_{had}(t)$ which can be measured experimentally via elastic scattering $\mu e \to \mu e$.

Approach: space-like evaluation

We propose to measure the running of $\alpha_{\mathrm{QED}}(t<0)$

$$a_\mu^{\mathrm{HLO}} = -\frac{\alpha}{\pi}\int_{-\infty}^{0}\frac{dt}{\beta t}\left(\frac{1-\beta}{1+\beta}\right)^2 \Delta\alpha_{\mathrm{had}}(t)$$

where $\beta = \sqrt{1-4m_\mu^2/t}$

$\Delta\alpha_{\mathrm{had}}(t)$ is the hadronic contribution to the running of

$$\alpha_{\mathrm{QED}}(q^2) = \frac{\alpha}{1-\Delta\alpha(q^2)}$$

evaluated in the space-like region (negative transfer momenta *t*) where it is a smooth function.

Approach: space-like evaluation

$$a_\mu^{\rm HLO} = \frac{\alpha}{\pi}\int_0^1 dx\,(x-1)\bar{\Pi}_{\rm had}(t(x)) = \frac{\alpha}{\pi}\int_0^1 dx\,(1-x)\Delta\alpha_{\rm had}(t(x))$$

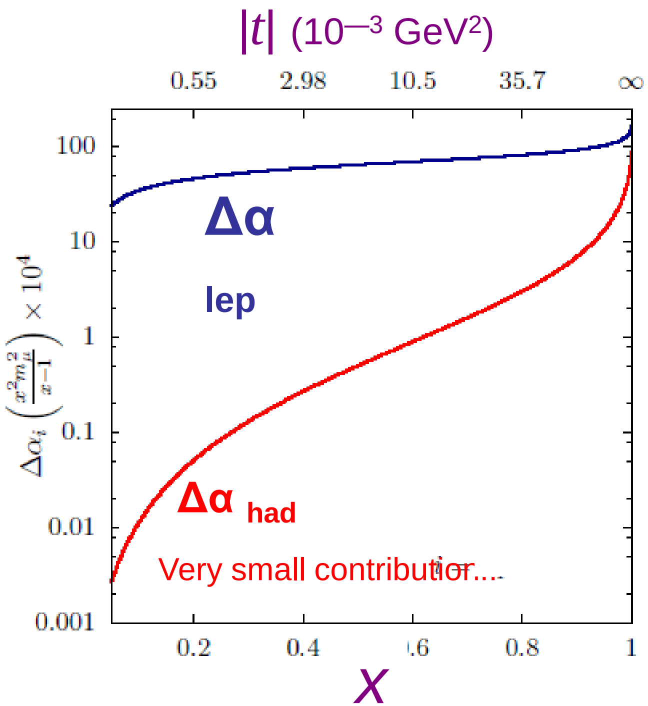
$$t(x) = -\frac{x^2 m_\mu^2}{1-x} \qquad t = \begin{cases} 0^- & \text{for } x \to 0^+ \\ -\infty & \text{for } x \to 1^- \end{cases}$$

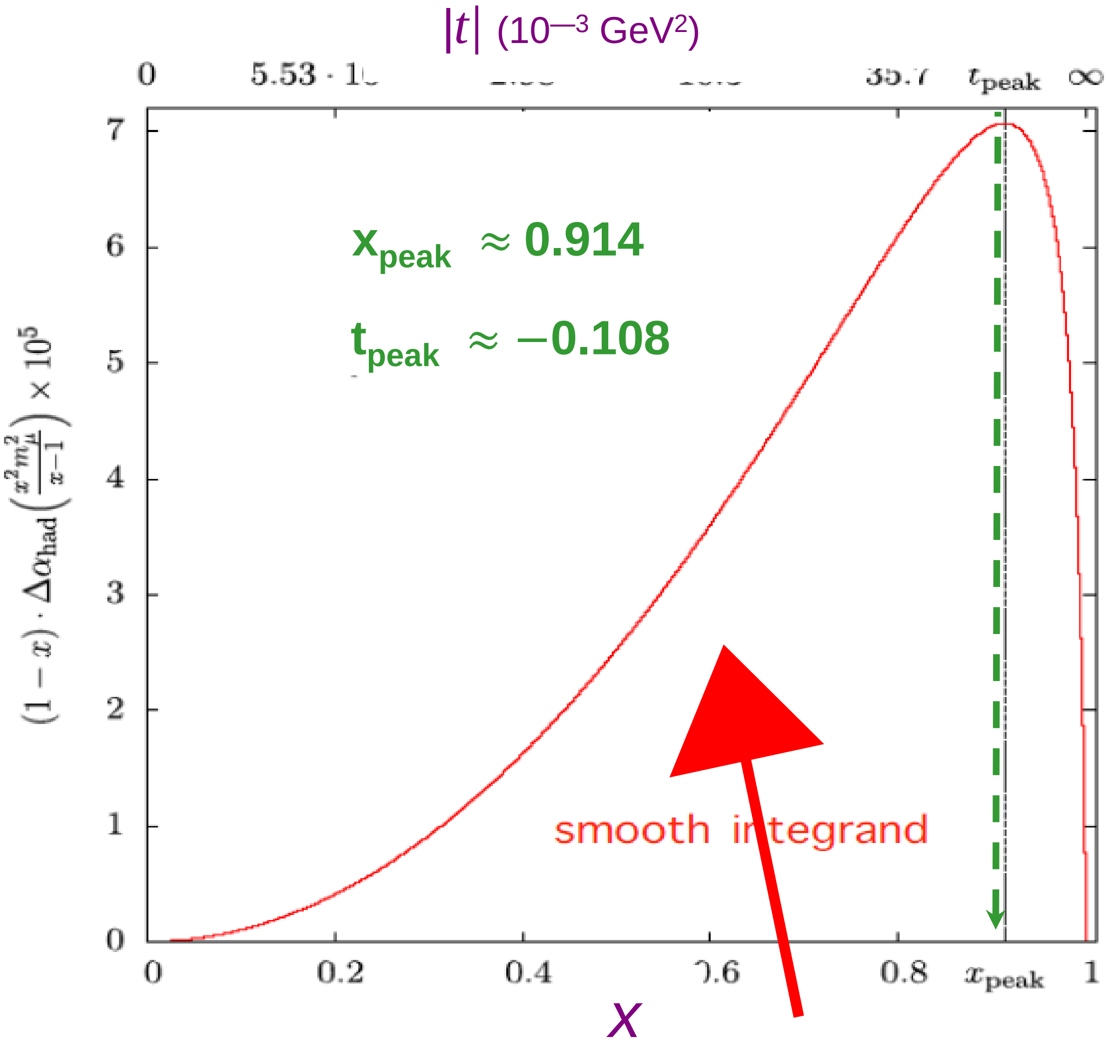
$$\alpha(t) = \frac{\alpha}{1-\Delta\alpha_{\rm other}(t)-\Delta\alpha_{\rm had}(t)}$$

Strategy:

measure $\Delta\alpha_{\rm had}(t)$ in the reachable experimental kinematic range
fit $\Delta\alpha_{\rm had}(t)$
get large |t| values from theory
get the integrand function and the value of $a_\mu^{\rm HLO}$

Approach: space-like evaluation





integrand function $(1-x)\Delta\alpha_{\rm had}(t(x))$

a_{HAD} is the total area under this curve

Why μ + e ⟶ μ + e ?

$\Delta\alpha_{HAD}(t)$ also from Bhabha events at low energy e+e- colliders

Muon scattering on a low Z target looks an ideal process:

★ It is a pure t-channel process

$$\frac{d\sigma}{dt} = \frac{d\sigma_0}{dt}\left|\frac{\alpha(t)}{\alpha}\right|^2$$

★ A high intensity (1.3 x 107 *μ/s*) muon beam is available in the North area at CERN. With Ebeam ~ 150 GeV:

$$-0.143 \lesssim t < 0 \text{ GeV}^2 \qquad 0 < x \lesssim 0.93$$ *spans the peak)*

★ The highly boosted kinematics allows to access the full kinematic range

★ The same detector can cover signal ($x > 0.4 - 0.5$) and normalization ($x \leq 0.3$) regions

The kinematics

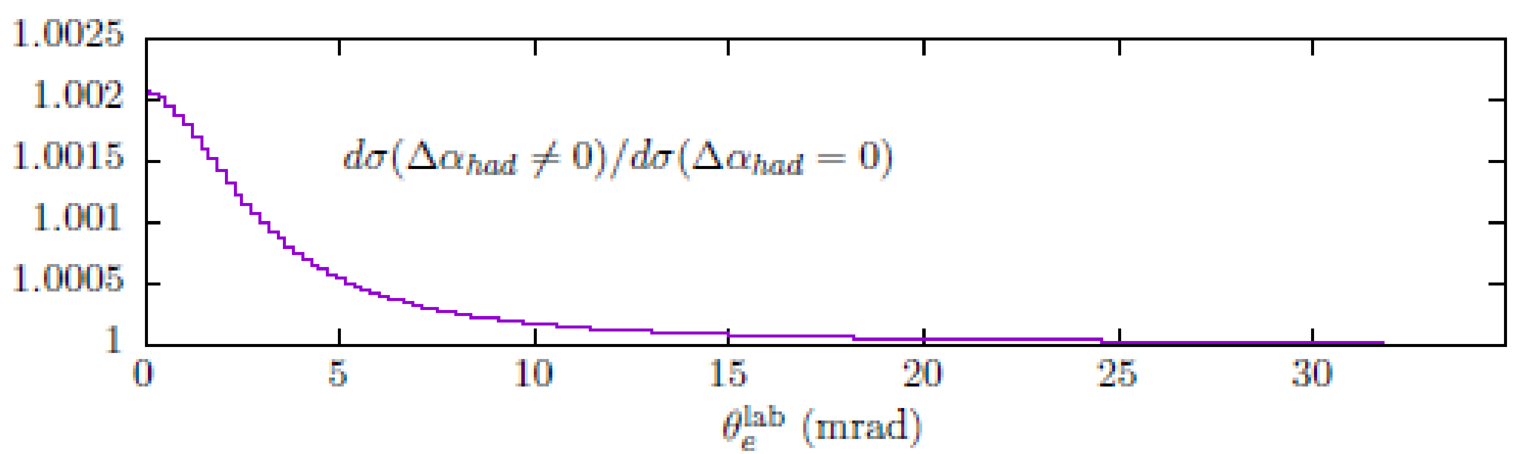
$$t = 2m_e^2 - 2m_e E_e, \qquad s = m_\mu^2 + m_e^2 + 2m_e E_\mu^i$$

$$E_e = m_e \frac{1 + r^2 c_e^2}{1 - r^2 c_e^2}, \qquad \theta_e = \arccos\left(\frac{1}{r}\sqrt{\frac{E_e - m_e}{E_e + m_e}}\right)$$

$$r \equiv \frac{\sqrt{(E_\mu^i)^2 - m_\mu^2}}{E_\mu^i + m_e}$$

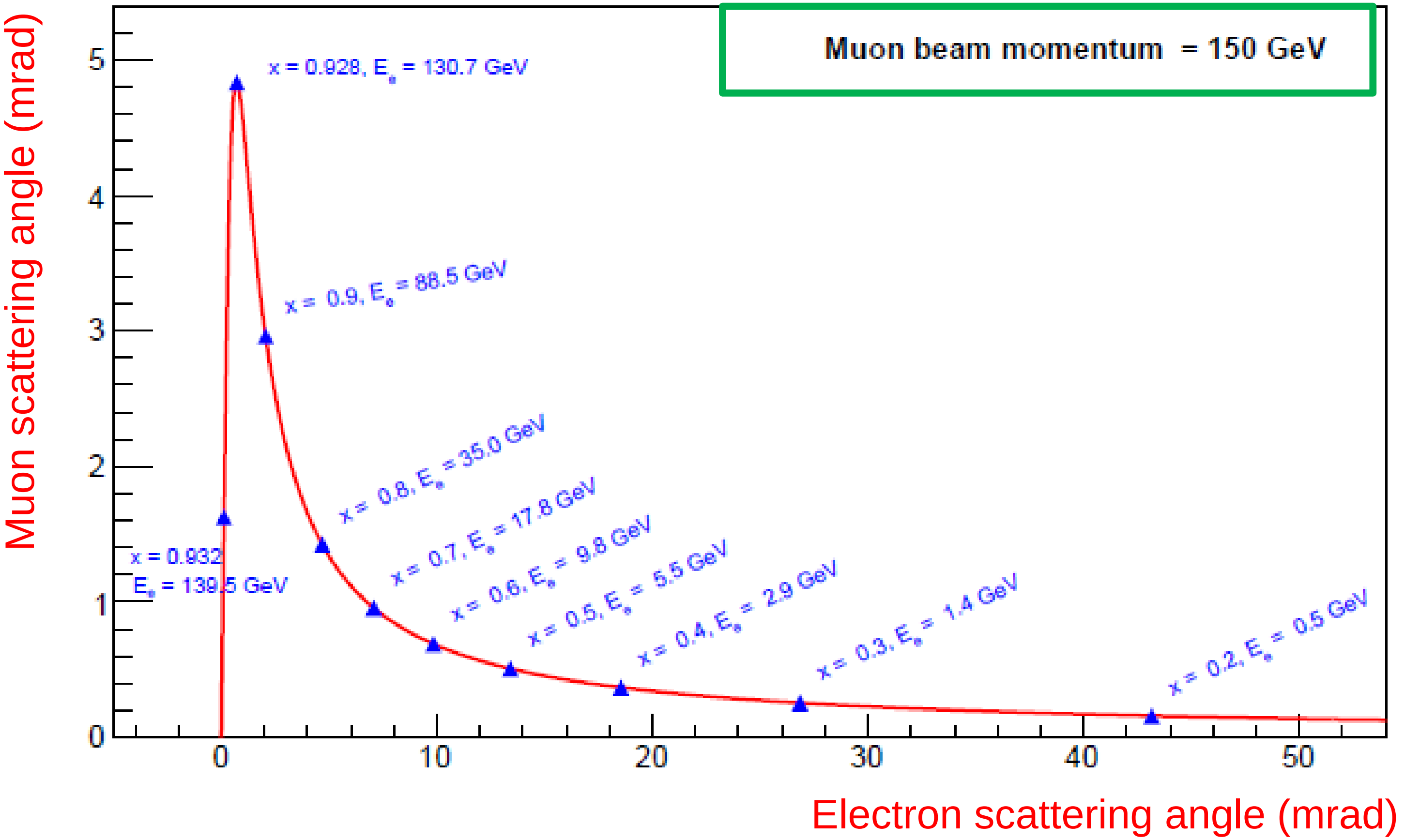
$$c_e \equiv \cos\theta_e$$

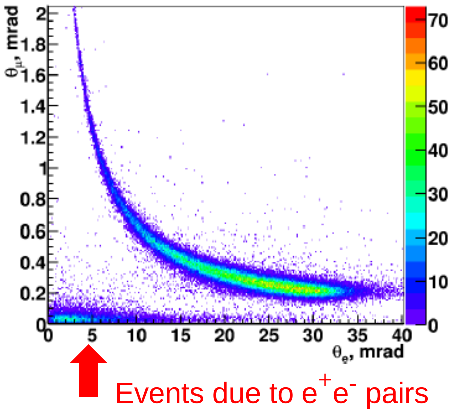
→ effect due to $\Delta\alpha_{\rm had}(t)$



The kinematics: *correlation curve*

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





The constraint is useful to select elastic events, reject background and reduce systematics in *t* determination
Below 2-3 mrad *μ* and *e* overlap, to be resolved by *μ/e* identification
Multiple scattering breaks the correlation: simulation and data will help to optimize the detector and reduce the systematics

Tools to do the measurement

A high energy muon beam *(must cover the t range needed)*

M2 beam seems to have the characteristics **(E_{μ}=150 GeV, 1.3x10^7 μ/s)** adequate for such a measurement.

The target : atomic electrons must be provided by a light material,

to minimize the e.m. interactions inside the target, but at the same time must provide a high enough number of target electrons

Berillium (under study with GEANT, or eventually Carbon)

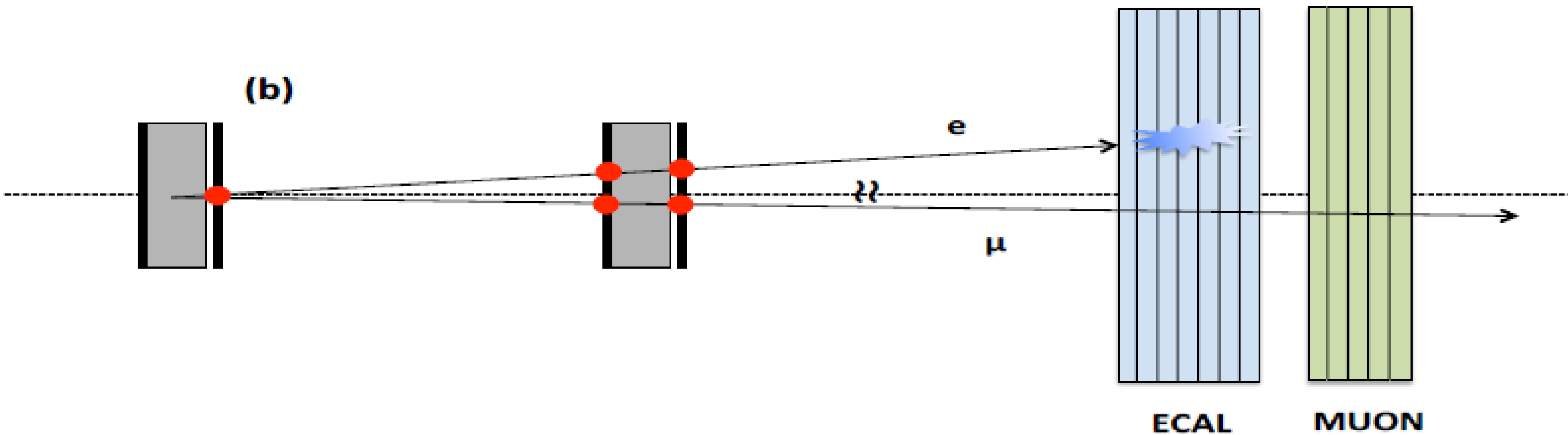
The detector setup:

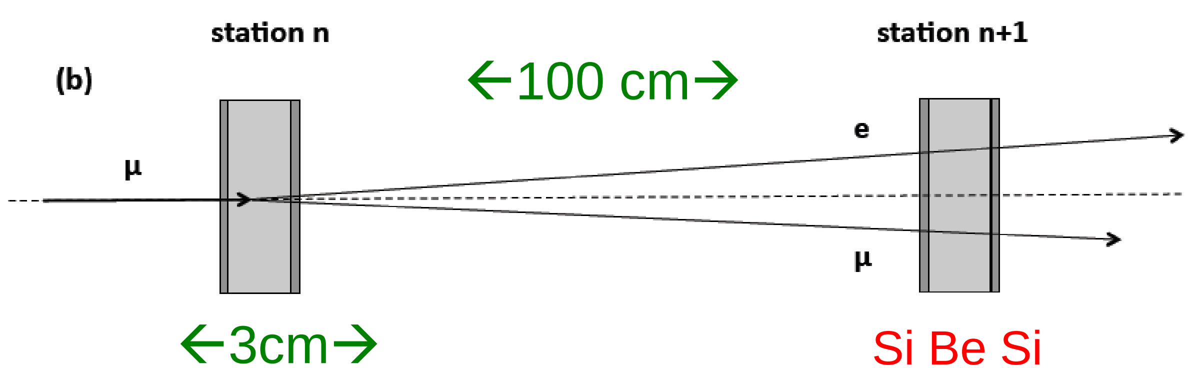
- a modular target made by 20 layers of Be (C) 3 (2) cm thick, sandwiched in layers of Si tracking planes.
- Need to measure very precisely the angles of the outcoming muons and electrons (to exploit kinematical correlation of the μ-e collision)
- Need to measure energy and direction of the incoming muon (a la COMPASS or NA62 GTRK)
- a simple PID (e.m. calorimeter and muon system) will be necessary

c.f.plot

Tools to do the measurement

Target elements are sandwiched between Si planes and spaced by ~ 100 cm air





Tools to do the measurement

Statistics

Expected statistics achievable assuming:

the μ beam **M2** with 1.3×10^{7} μ/s , running time 2×10^{7} s/yr

20 layers of 30 mm Be target → 60 cm Be

Lumi ~ 0.8×10^{7} nb^{-1} /yr

➡ ~ **2×10^{12}** events /yr (will allow to have a statistical precision of 0.3 % on a_μ^{HLO} in two years running)

But…….

This is an experiment where the main issue is to control the systematic error at the same level as the statistical one

➡ *Most serious contribution identified up to now is the multiple scattering of low energy electrons (O(few GeV))*

What could we learn from COMPASS??

Are elastic events triggered and detected? How do they show up?

With which angular precision are muons and electrons measured?

Are there muons + n electrons in the final state?

What precision is achieved in the Luminosity measurement?

How well is an incoming muon measured? *(momentum, direction,time)*

……………………………………………

Tentative timeline

Studies with GEANT 4 under way to study:

geometrical configuration
target modularity and thickness
number of tracking Si planes
need to have particle identification

~ 1 year

Plan to have exploratory beam tests:

first one in 2017 using an existing setup in area 128 (H8 beam)

TB in 2017

~ 2 years

Once the optimization is made:

detector elements: Hamamatsu sensors, existing r/o electronics,
explore if existing calorimeters&muon system can be re-used,

~ ? ? ? years

➡ In the meanwhile try to build a collaboration !