Progetti - Flavor

F. Renga, C.Voena

Retreat di Fisica delle Particelle Elementari

Assisi, 16-18 Giugno 2019

Istituto Nazionale di Fisica Nucleare

Flavor Physics

- Probe New Physics at very high energy scales: $\Lambda > 10^2$-10^4 TeV
- High intensity frontier: complementarity with High energy frontier (LHC)
- *Flavor is the usual greveyard of BSM EW theory* (European strategy @Granada)

Topics

Rare μ and τ decays: Charged lepton flavor violation

Heavy flavor: b and c Physics

g-2, EDM, oscillazioni n-nbar, Higgs..

Note:
Logos show groups present at INFN-Roma1/Sapienza

Muon very rare processes

MEG group @ INFN Roma1/Sapienza (+ PI/PV/GE/LE)
Other INFN groups active in Mu2e (Pisa Lecce)

μ→e transition processes

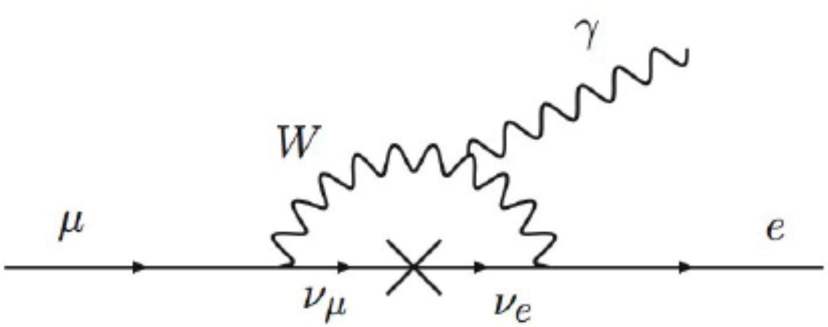
- Practically forbidden in the SM: BR~10^{-54}
- Enhanced in many New Physics models

$$\mu^- N \rightarrow e^- N$$

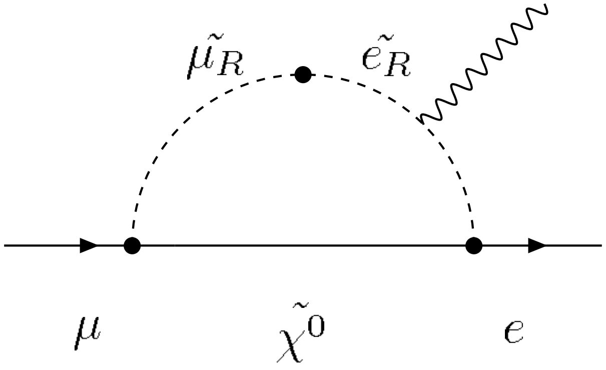
$$\mu^+ \rightarrow e^+ \gamma$$

$$\mu^+ \rightarrow e^+ e^+ e^-$$

Standard Model

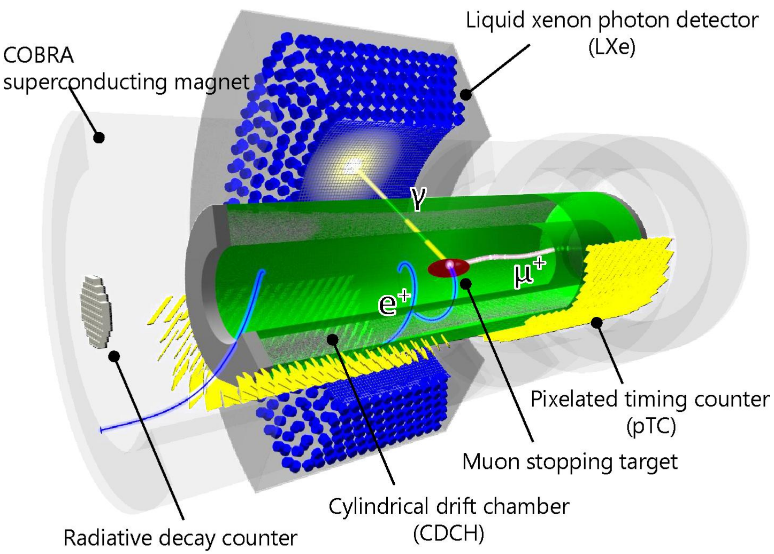


New Physics (example)

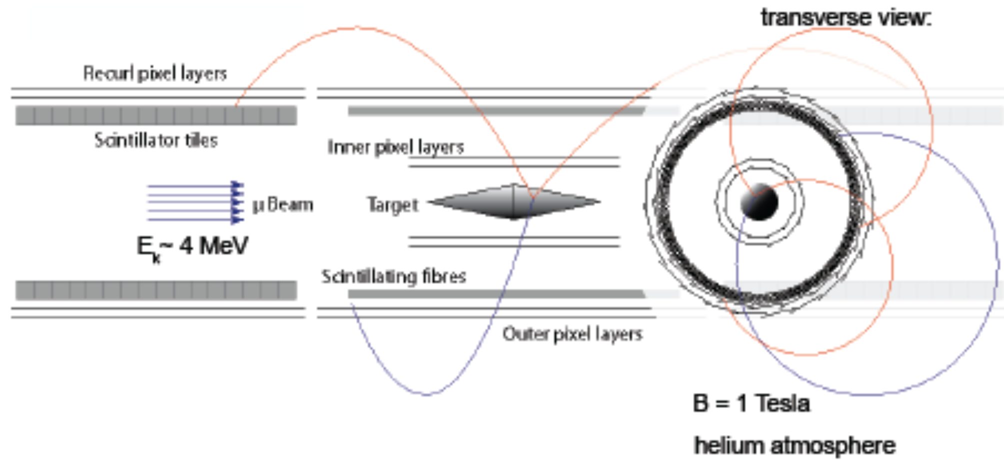


μ→e experiments

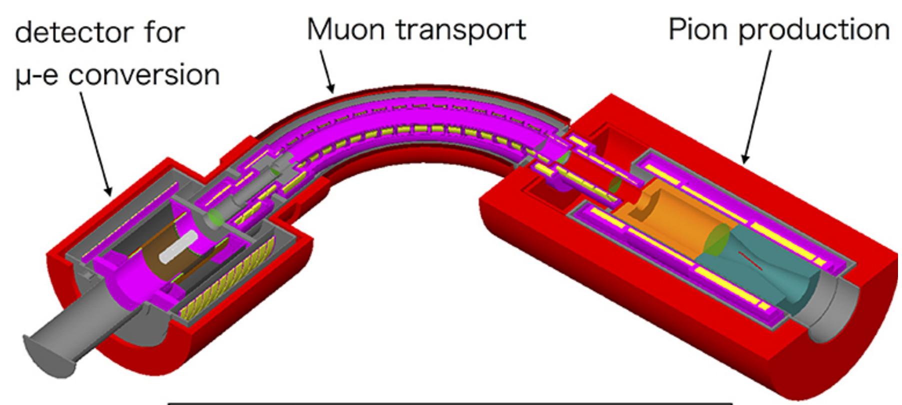
MEG-II (PSI)



Mu3e (PSI)

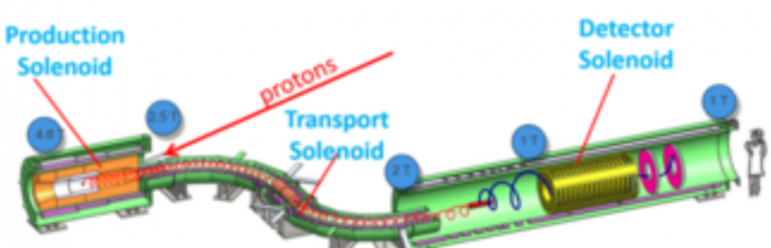


COMET (J-Park)



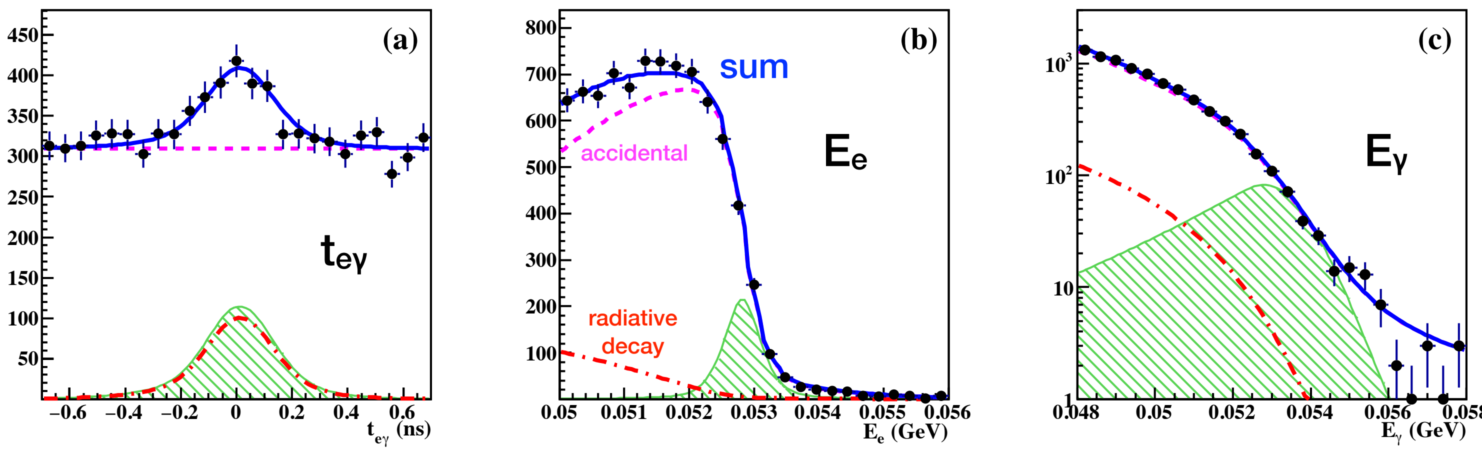
COMET Phase-I Layout

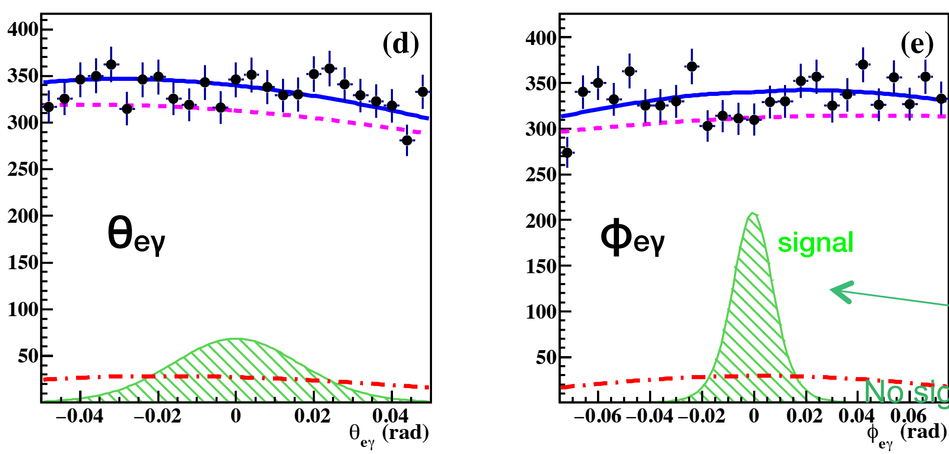
Mu2e (Fermilab)



MEG result

- 7.5 x 10^{14} stopped muons in 2009-2013
- 5 discriminating variables: E_e, E_γ, $T_{e\gamma}$, $\theta_{e\gamma}$, $\varphi_{e\gamma}$
- Likelihood analysis + frequentistic approach





BR (μ→eγ) < 4.2x 10^{-13} at 90% C.L.

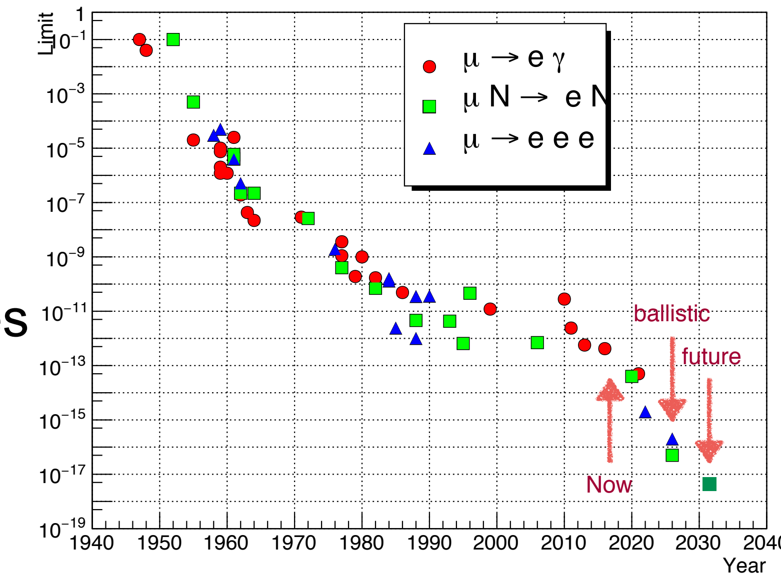
Eur.Phys.J.C76 (2016)

Magnified signal for illustrative purposes

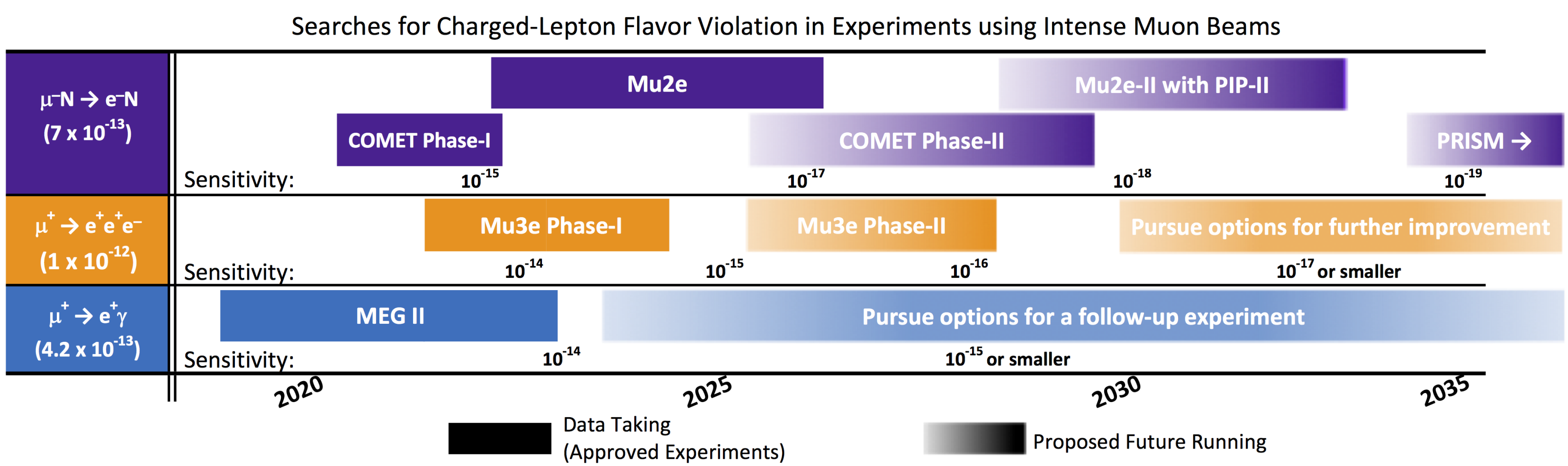
No significant excess of the signal

μ→e present and future plans

- Mu2e and Mu3e are structured in different phases and upgrades have been proposed
- For μ->eγ, preliminary (simulation) studies have been performed for future experiment (after MEG-II)



European strategy update @ Granada



MEG @Roma1: expertise

- The MEG Rome group participated also in the MEG experiment (since 2007, timing counter, positron reconstruction, likelihood analysis)

MEG-II

Prototyping phase for Drift Chamber +HV+gas+reco

Crucial support from LABE, mechanical shop, CAD service

Very good expertise with gaseous detector (complementary to those already present in Rome ..GEM, MPGD, RPC)

MEGII @Roma1

G. Cavoto
G. Chiarello (assegnista)
M. Gianfelici (laureanda)
M. Meucci (dottorando)
V. Pettinacci
F. Renga
C. Voena

Target position measurement system

Cooling system for CW target (search for X-boson 17.6 MeV)

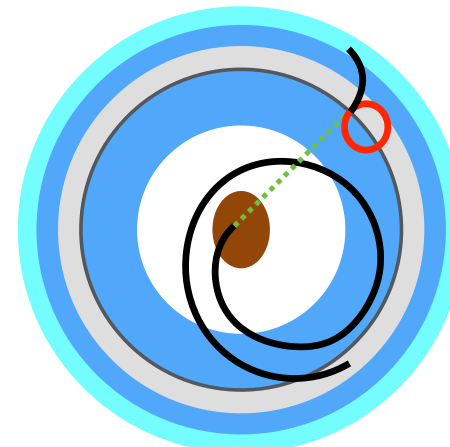
need specialized engineer:

V.Pettinacci

μ→eγ perspectives

- The Rome group is considering future perspectives for μ→eγ experiments:

  - currently limited by accidental background
  - with an improvement of the resolutions and a conversion techinque we can improve the sensitivity by one order of magnitude

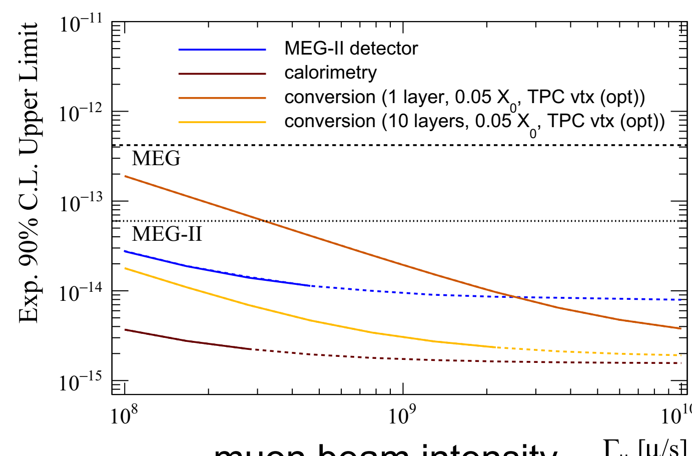


- Activity around the world to increase intensity of muon beam to 10^9-10^{10} muon/s

  - PSI
  - Fermilab (PIP-II)
  - RCNP

potential synergy with Ph.D. in Accelerator Physics?

Eur. Phys. J.C 78, 37 (2018)
G. Cavoto et al.



muon beam intensity

New Physics reach

arXiv:170203020
A. Crivellin et al.

	$\mathrm{Br}(\mu^+ \to e^+\gamma)$		$\mathrm{Br}(\mu^+ \to e^+e^-e^+)$		$\mathrm{Br}^{\mathrm{Au/Al}}_{\mu\to e}$	
	$4.2 \cdot 10^{-13}$	$4.0 \cdot 10^{-14}$	$1.0 \cdot 10^{-12}$	$5.0 \cdot 10^{-15}$	$7.0 \cdot 10^{-13}$	$1.0 \cdot 10^{-16}$
C_L^D	$1.0 \cdot 10^{-8}$	$3.1 \cdot 10^{-9}$	$2.0 \cdot 10^{-7}$	$1.4 \cdot 10^{-8}$	$2.0 \cdot 10^{-7}$	$2.9 \cdot 10^{-9}$
$C_{ee}^{S\,LL}$	$4.8 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	$8.1 \cdot 10^{-7}$	$5.8 \cdot 10^{-8}$	$1.4 \cdot 10^{-3}$	$2.1 \cdot 10^{-5}$
$C_{\mu\mu}^{S\,LL}$	$2.3 \cdot 10^{-7}$	$7.2 \cdot 10^{-8}$	$4.6 \cdot 10^{-6}$	$3.3 \cdot 10^{-7}$	$7.1 \cdot 10^{-6}$	$1.0 \cdot 10^{-7}$
$C_{\tau\tau}^{S\,LL}$	$1.2 \cdot 10^{-6}$	$3.7 \cdot 10^{-7}$	$2.4 \cdot 10^{-5}$	$1.7 \cdot 10^{-6}$	$2.4 \cdot 10^{-5}$	$3.5 \cdot 10^{-7}$
$C_{\tau\tau}^{T\,LL}$	$2.9 \cdot 10^{-9}$	$9.0 \cdot 10^{-10}$	$5.7 \cdot 10^{-8}$	$4.1 \cdot 10^{-9}$	$5.9 \cdot 10^{-8}$	$8.5 \cdot 10^{-10}$
$C_{\tau\tau}^{S\,LR}$	$9.4 \cdot 10^{-6}$	$2.9 \cdot 10^{-6}$	$1.8 \cdot 10^{-4}$	$1.3 \cdot 10^{-5}$	$1.9 \cdot 10^{-4}$	$2.7 \cdot 10^{-6}$
$C_{bb}^{S\,LL}$	$2.8 \cdot 10^{-6}$	$8.6 \cdot 10^{-7}$	$5.4 \cdot 10^{-5}$	$3.8 \cdot 10^{-6}$	$9.0 \cdot 10^{-7}$	$1.2 \cdot 10^{-8}$

.....

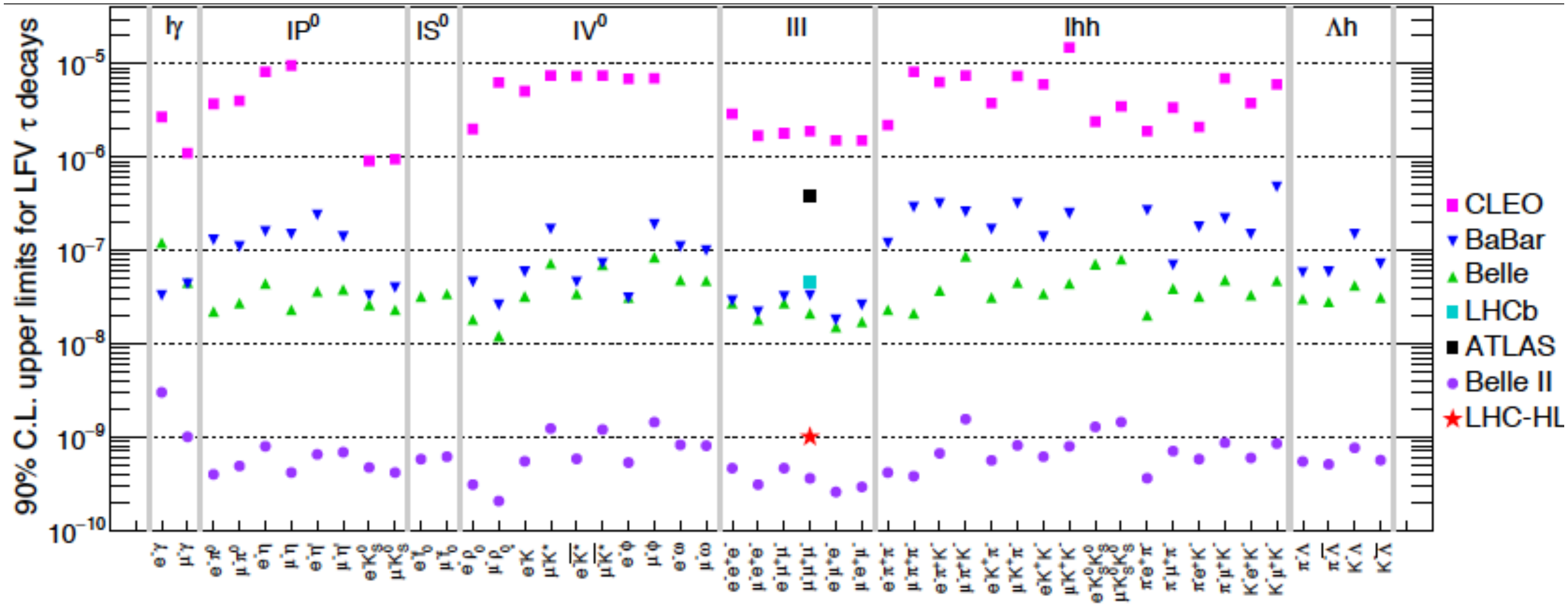
Limits on the Wilson Coefficients of LFV effective operators from present and future cLFV muon processes

τ rare decays

Groups @Roma1 are not currently involved in τ analysis

τ rare decays

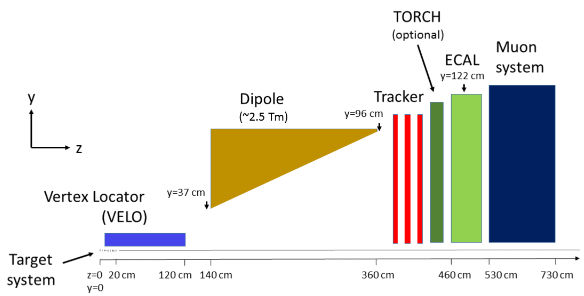
- As for muons, charged lepton flavor decays pratically forbidden in the SM



- B-factories expected to be the most powerful tool to constrain these decays (currently Belle-II)
- Presently many LFV studies also at LHC (LHCb ATLAS CMS)
- Opportunities also at HL-LHC and HE-LHC: arXiv:1812.07638

τ possible future facilities (E.strategy)

- Super Charm tau factory
- TauLFV @Ship Beam line
  - Benchmark mode: $\tau \rightarrow 3\mu$
  - Enormous τ production rate
  - Charm Physics



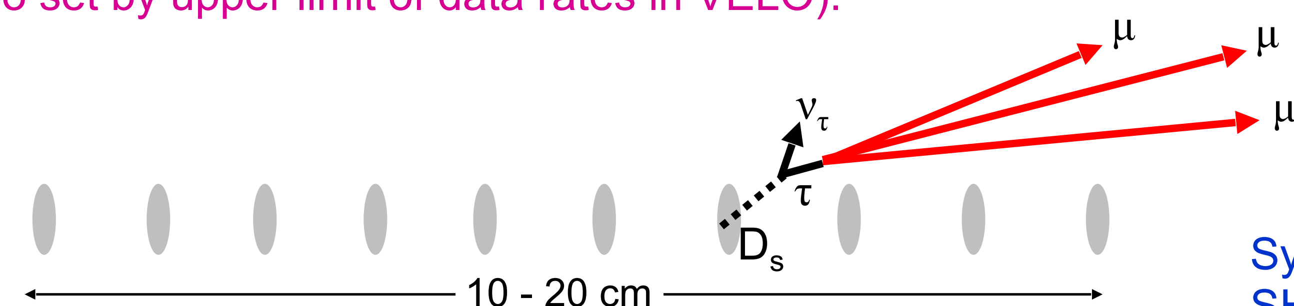
- Interest @Roma1

- We are in contact with the CERN group

- Possible envisaged contributions in muon detector and reconstructions?

(At the moment this item is not covered, we have the necessary expertise)

design dedicated experiment upstream of SHiP, with thin, distributed targets, to bleed off ~2% of the beam intended for SHiP → 2 mm of tungsten (this value also set by upper limit of data rates in VELO).



Synergetic with SHiP operation !

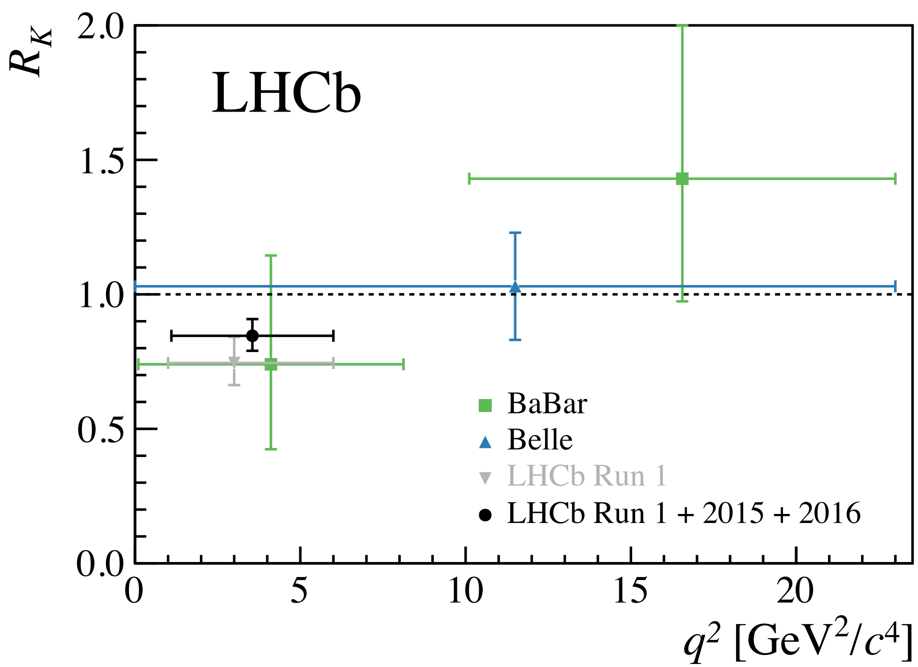
The heavy hadron sector (b, c)

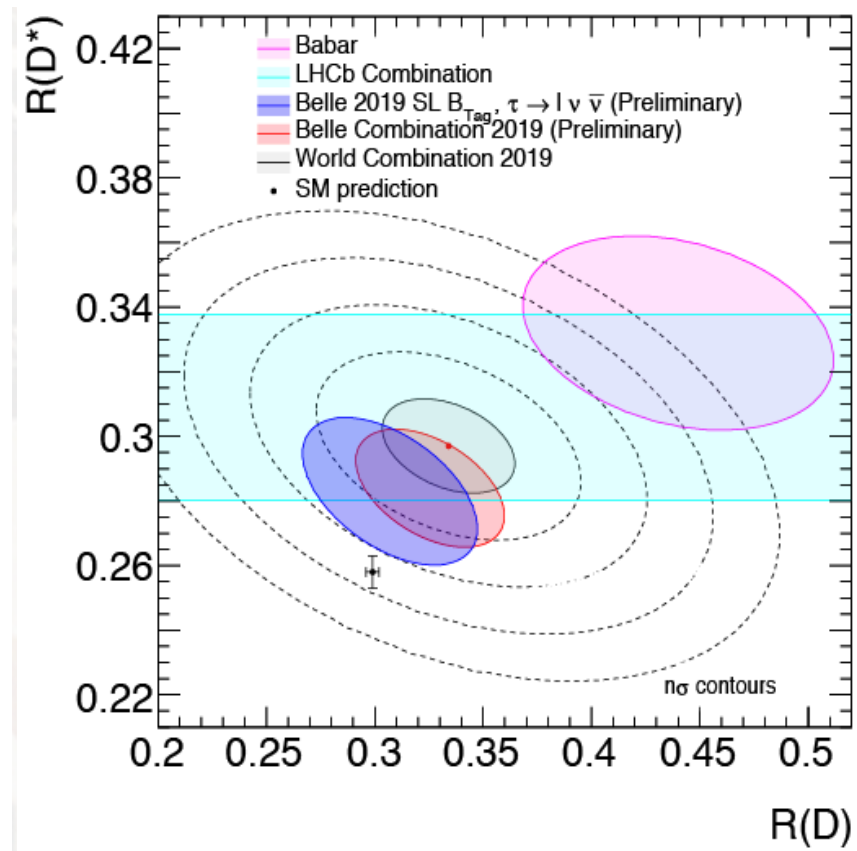
LHCb & Babar & Belle-II @ Roma1
CMS & ATLAS Rome group not involved in flavor Physics

B anomalies @ Moriond EW 2019

$$R_{K^{(*)}} = \frac{B(B \to K^{(*)}\mu^+\mu^-)}{B(B \to K^{(*)}e^+e^-)} = 1(SM)$$

$$R(D^{(*)}) = \frac{B(\overline{B} \to D^{(*)}\tau^-\overline{\nu_\tau})}{B(\overline{B} \to D^{(*)}\ell^-\overline{\nu_\tau})} (\ell = e,\mu)$$





Unitarity triangle

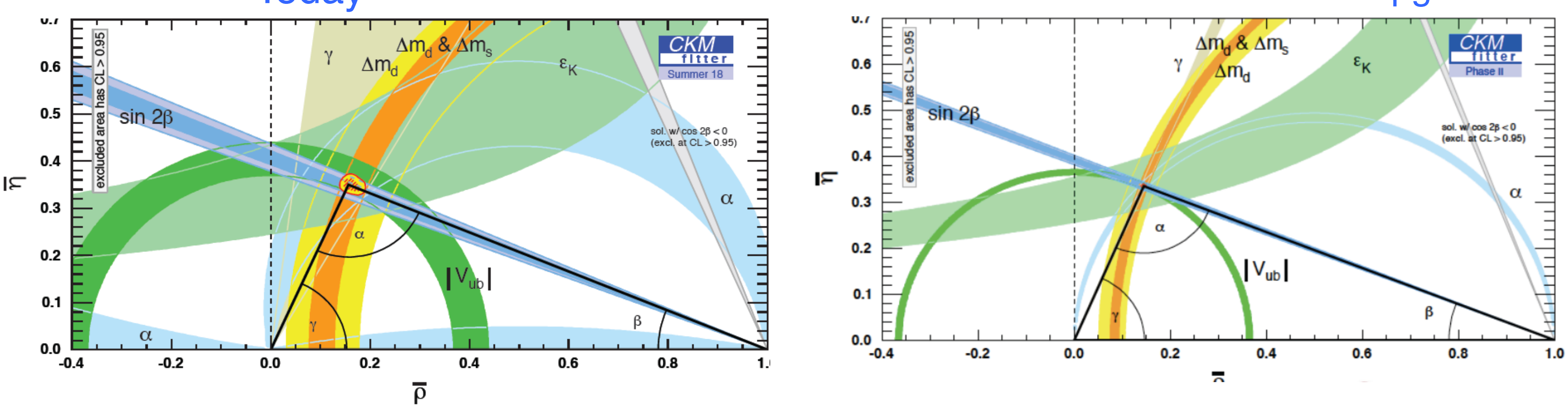
- The elements of the CKM matrix are fundamentals parameters and must be measured as precisely as possible

- Overconstrain to check of possibile New Physics contributions

$$V_{\mathrm{CKM}} = \begin{pmatrix} 0.97446 \pm 0.00010 & 0.22452 \pm 0.00044 & 0.00365 \pm 0.00012 \\ 0.22438 \pm 0.00044 & 0.97359^{+0.00010}_{-0.00011} & 0.04214 \pm 0.00076 \\ 0.00896^{+0.00024}_{-0.00023} & 0.04133 \pm 0.00074 & 0.999105 \pm 0.000032 \end{pmatrix}$$

Today

End of HL-LHC: Belle II + LHCb Upgrade II

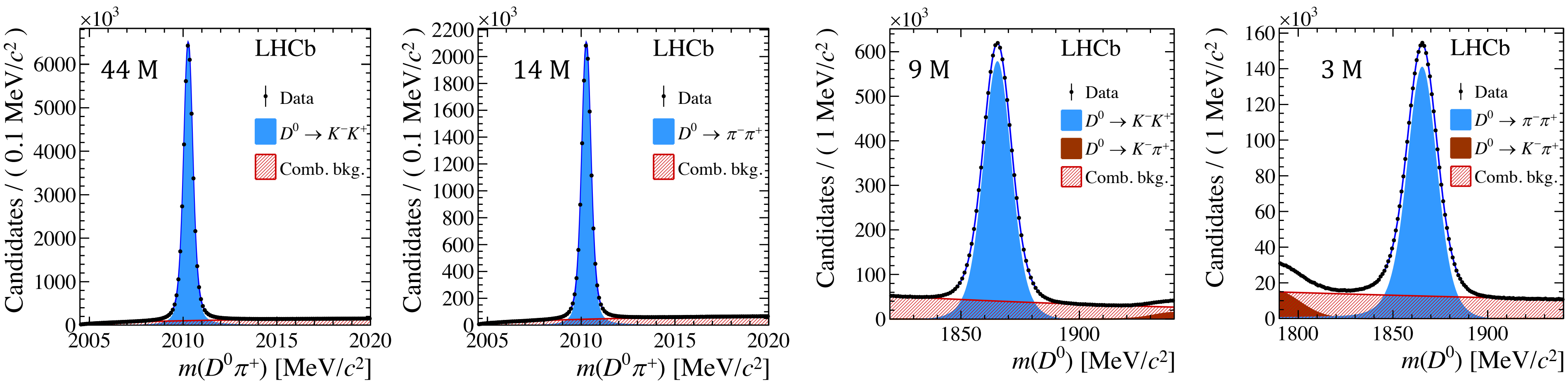


CPV in charm

Observation of CP violation @5.3σ
in $D^0 \to \pi\pi$ and $D^0 \to KK$ decays

soft pion tag

muon tag



Run2 only

Run2 + Run1

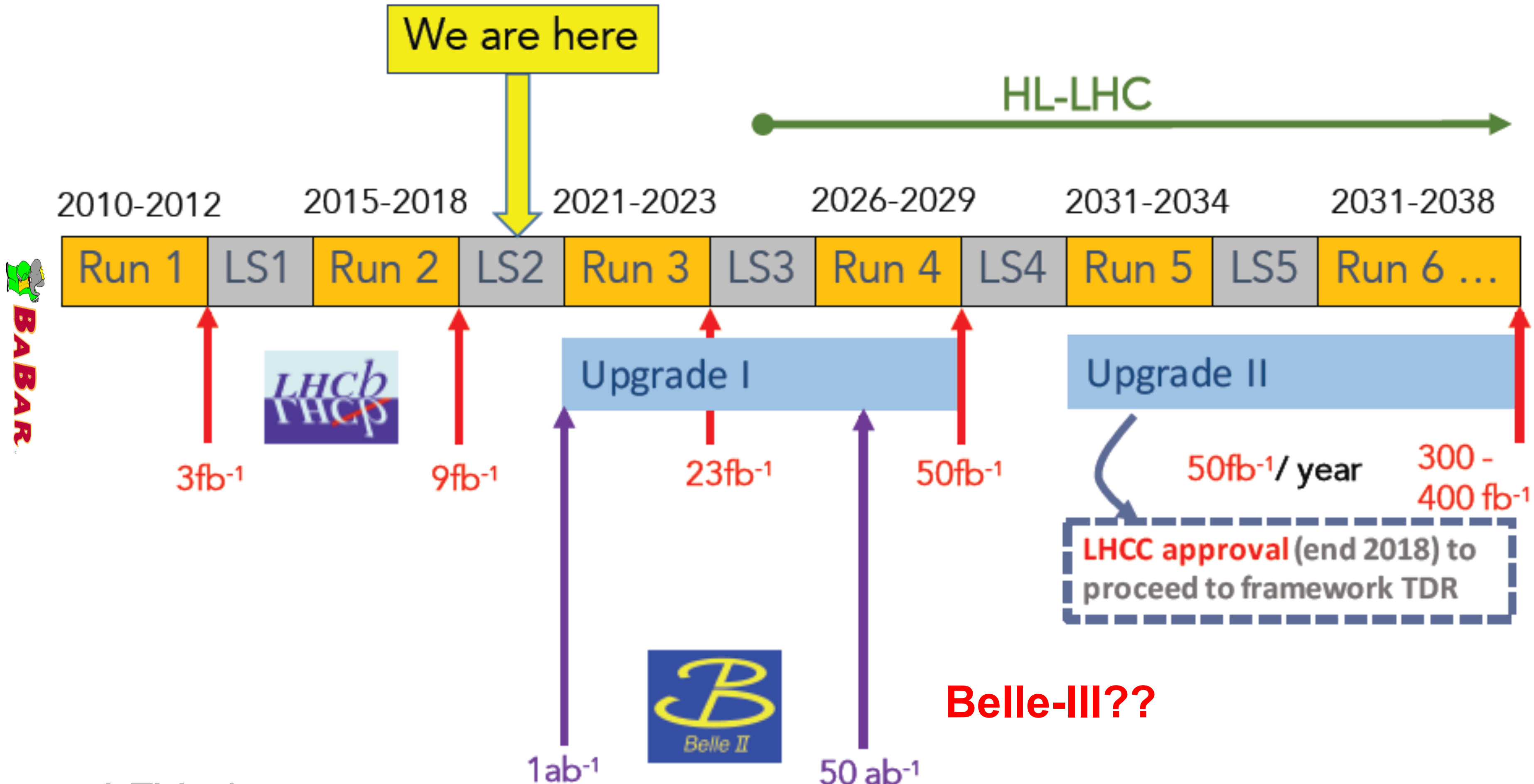
$$\Delta A_{CP}^{\pi-\mathrm{tagged}} = [-18.2 \pm 3.2\,(\mathrm{stat.}) \pm 0.9\,(\mathrm{syst.})] \times 10^{-4}$$
$$\Delta A_{CP}^{\mu-\mathrm{tagged}} = [-9 \pm 8\,(\mathrm{stat.}) \pm 5\,(\mathrm{syst.})] \times 10^{-4}$$

$$\boldsymbol{\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}}$$

CP violation observed at $\boldsymbol{5.3\sigma}$!!

Present & future

European strategy update @ Granada



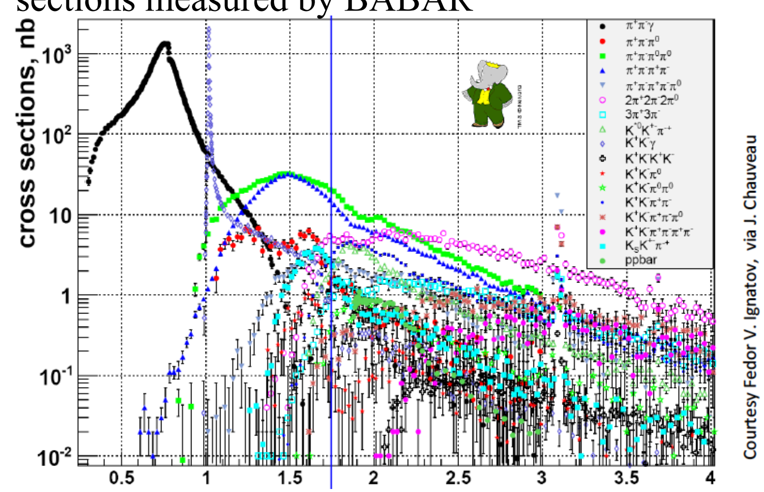
- τLFV, charm-tau

Long term future: (>20 y) Flavor physics @ FCC-ee running at the Z pole => unique potential for b decays (also for τ)

Babar @ Roma1

- *BABAR* data taking stopped in 2008, but Collaboration still active
- **F. Anulli @ Roma**
- 10 papers published last year. More than 20 analyses ongoing. Main target analysis:
  - $B \rightarrow D^{*} \tau \nu$ with Semileptonic tag
  - Measurement of $e^{+}e^{-} \rightarrow \pi^{-}\pi^{+}$ cross section for $(g\text{-}2)_{\mu}$ calculation
- Plan to continue data analysis until Belle II will accumulate significantly higher statistics (very likely, not before than mid 2021)
- "sigla" in CSN1 closed a few years ago. Minimal support for conferences granted.
- *BABAR* in Rome:
  - CPV in $D^{+} \rightarrow \pi^{+}\pi^{0}$ decays, by Alessandro Pilloni, now with a theory postDoc in Trento
  - Measurement of Collins asymmetries (polarized fragmentation functions), by F. Anulli
  - Physics analysis coordination (F. Anulli)

A not exhaustive compilation of hadronic cross sections measured by BABAR



Belle-II @ Roma1

- **F.Ameli**

  - Collaboration with Napoli group for calorimeter electronic
  - Evaluating solutions for a possible upgrade
  - ENEA group (S.Baccaro) studying crystals for a possible upgrade
  - The experiment is taking data. Could be interest to join!

50 ab^{-1} in 2027
Future: Physics case under study

LHCB @ Roma1

- **Control system of the electronic for the muon system (UpgradeI)**

↓

LABE

- **Analysis: exotic charmonium**
  (e.g. X(3872)->J/ψω)

↓

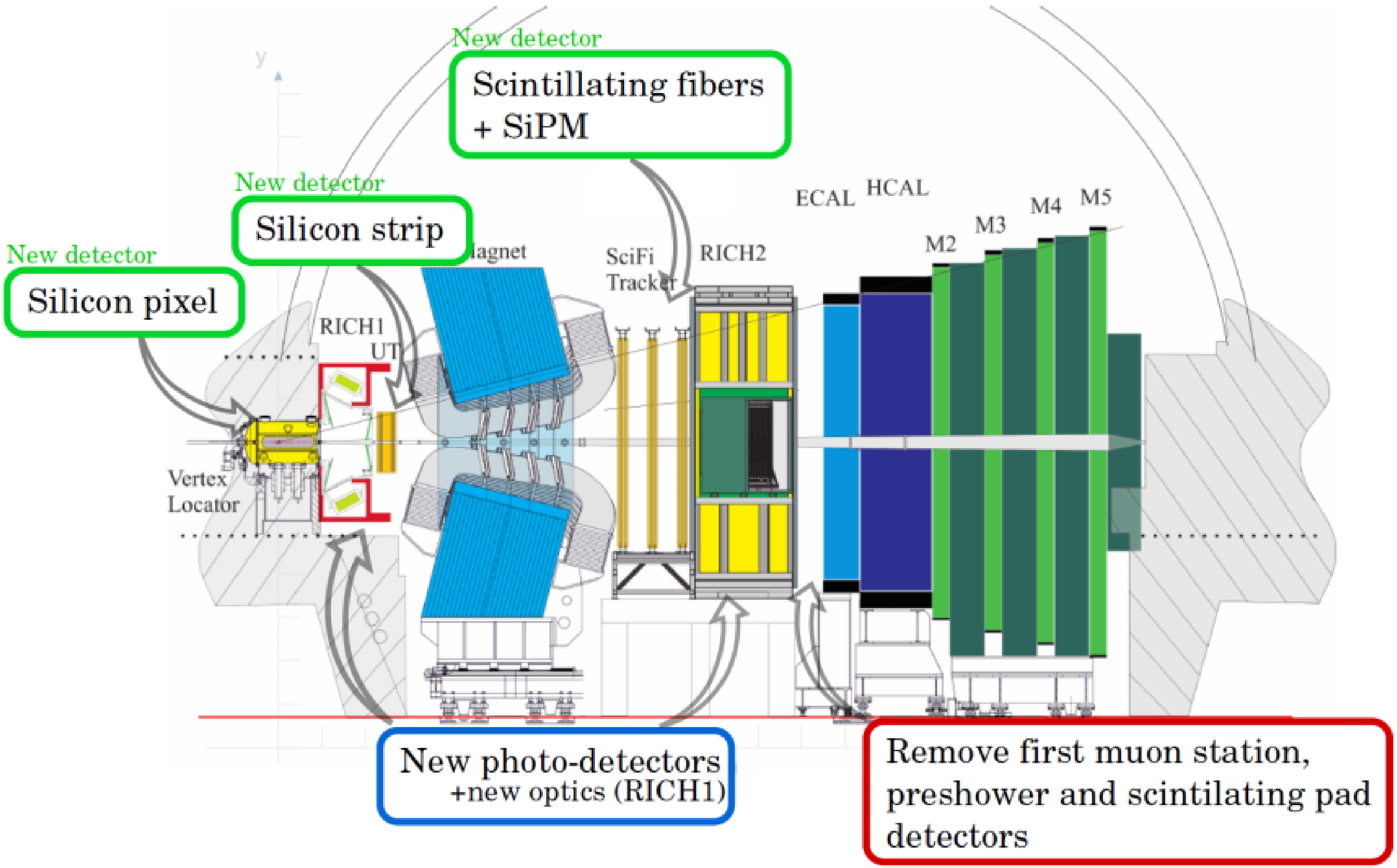
Server @ SICR

- **Expertise in gas detectors**
  MWPC, GEM..

LHCb @Roma1
V. Bocci
G. Martellotti
D. Pinci
R. Santacesaria
C. Satriano
A. Sciubba

Interest in muon detector for UpgradeII

LHCB Upgrade-I



+Upgraded electronics, trigger and data acquisition system

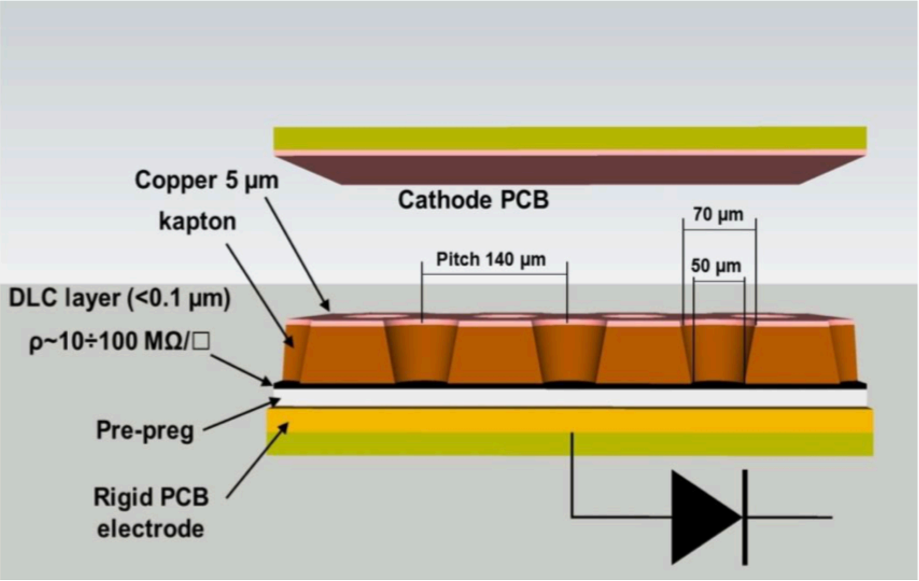
LHCB Upgrade-II – μRwell

- Preferred scenario: luminosity of $1.5*10^{34}$ cm^{-2} s^{-1}
- Stringent requirement on the muon detector
- The MWPC that currently instrument the 4 LHCb muon stations cannot substain the foreseen rate

Possible solution: μRwell

Expertise @ Roma1 in muon systems
LHCb group will participate in production and test

Possible synergy with τLFV



LHCB Upgrade-II – Physics reach

- Integrated luminosity 300 fb^{-1}

Table 10.1: Summary of prospects for future measurements of selected flavour observables for LHCb, Belle II and Phase-II ATLAS and CMS. The projected LHCb sensitivities take no account of potential detector improvements, apart from in the trigger. The Belle-II sensitivities are taken from Ref. [605].

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [606]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [607]
ϕ_s, with $B_s^0 \to D_s^+D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	150 mrad [94]	60 mrad	–	17 mrad	Under study [608]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [609]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [610]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

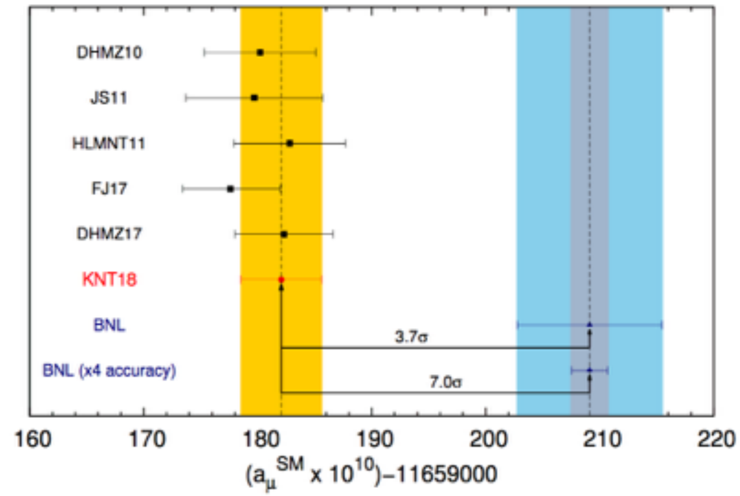
$\div 4$ $\approx$ $\div 4$

EDMs, g-2...

There are no groups involved @Roma1
(but other INFN groups are present)

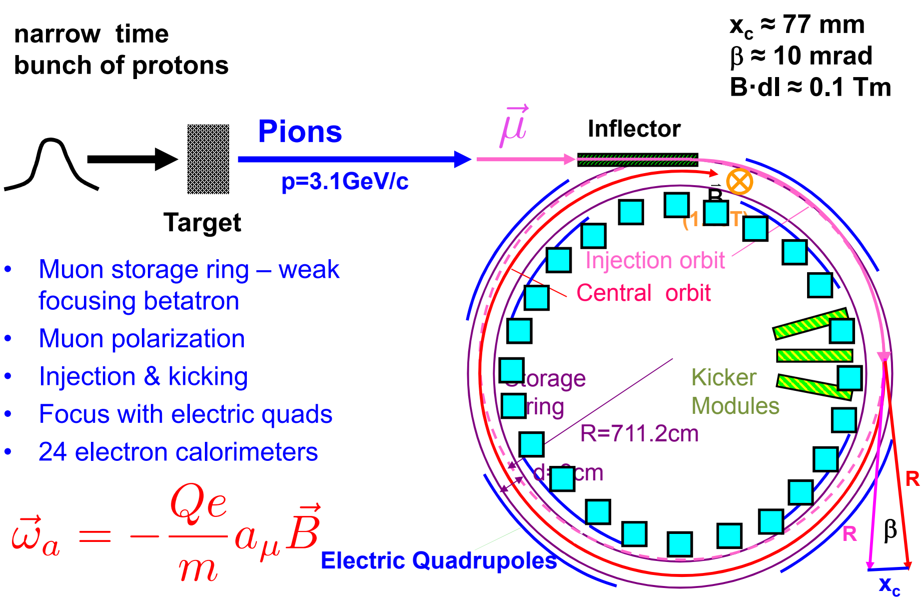
g_μ-2

- Current disagreement vs SM
- Muon EDM as byproduct



E989 @ Fermilab

- Expected sensitivity ~0.14ppm
- Expected first result end 2019 (BNL sensitivity)
- g_μ-2 is a byproduct

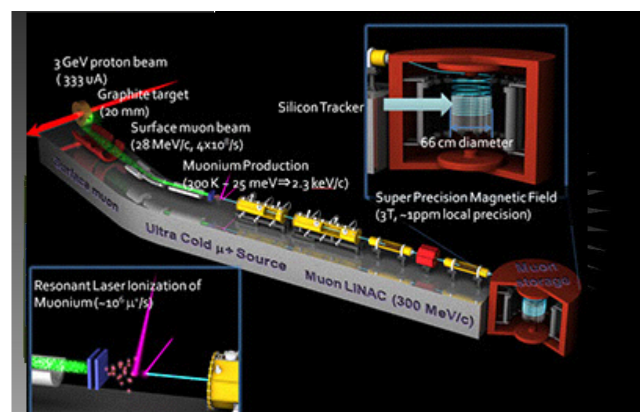


- Muon storage ring – weak focusing betatron
- Muon polarization
- Injection & kicking
- Focus with electric quads
- 24 electron calorimeters

$$\vec{\omega}_a = -\frac{Qe}{m} a_\mu \vec{B}$$

E34 @J-Park

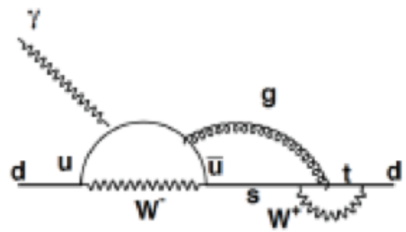
- Different experimental technique
- Timescale: > 2021
- 0.1ppm



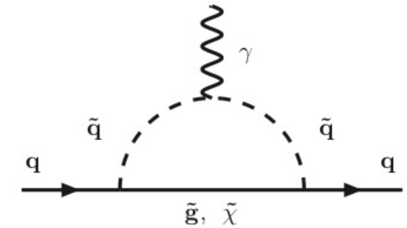
EDMs: n, e, μ, nuclei, atoms

- Strong and EW CP violation
- No SM background

SM



BSM



Neutron EDM

- present limit: $d_n < 2.9 \cdot 10^{-26} e \cdot cm$
- SM prediction: $d_n^{SM} \approx 10^{-31} e \cdot cm$

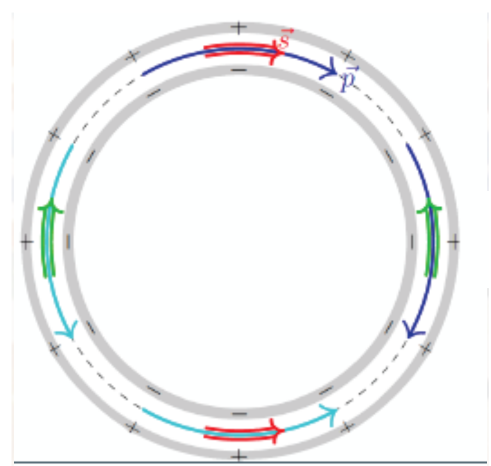
Reach: $d_n \approx 10^{-29} e \cdot cm$

Place	UCN source	sensitivity δd_n	time scale - start
ILL	^{4}He (SuperSANS) at reactor	10^{-27}	2019
PIK (Gatchina)	sD_2 at PIK reactor	$2 \cdot 10^{-28}$	2022
PSI	sD_2 at spallation source	10^{-27}	2019
TRIUMF	^{4}He at spallation source	10^{-27}	2020
SNS (Oak Ridge)	^{4}He at spallation source	$2 \cdot 10^{-28}$	2022
LANL	sD_2 at spallation source	$1-3 \cdot 10^{-27}$	2019
RCNP	^{4}He at spallation source	$few \cdot 10^{-27}$	?
JPARC	spallation source	?	?
TUM	sD_2 at FRMII reactor	10^{-28}	> 2022
ILL	stack of ^{4}He source/ EDM cells at reactor	10^{-29}	>2024
ESS	cold neutron beam	10^{-25}-10^{-26}	?

Proton EDM

New: All-electric storage rings
 => JEDI/CPEDM
 => plan: start costruction in 2027

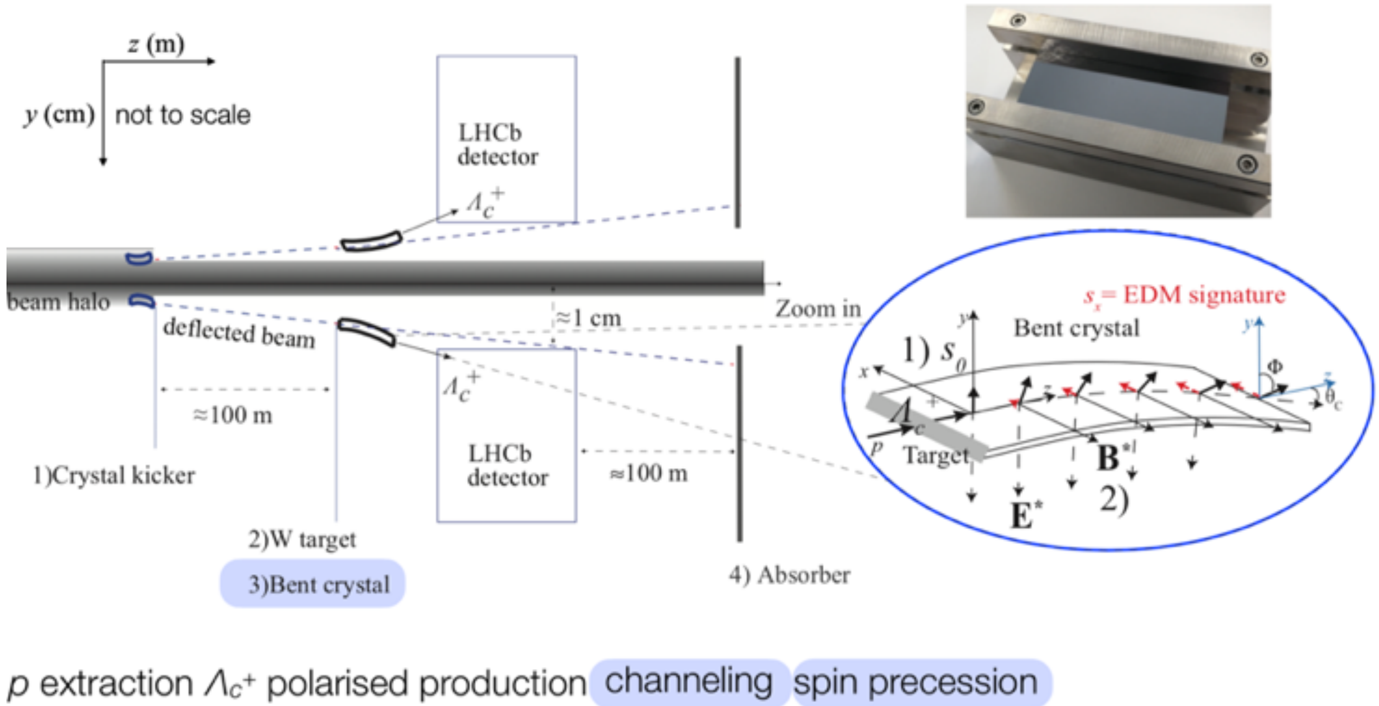
Reach: $d_p \approx 10^{-29} e \cdot cm$



Measuring baryons MDM & EDM

- EDM/MDM from spin precession of channeled baryons in bent crystals

Sensitive to g-2 of the particle



Large deflection (15 mrad) to enhance the precession effect and to send particles within the **LHC-b acceptance**

N.Neri, https://indico.cern.ch/event/755856/contributions/3260539/attachments/1779601/2895655/Neri_PBCJan19.pdf

Summary

- Flavor Physics: a lot of activity and many projects for the **middle-term** future under consideration

- Rome groups very active in Flavor Experiments:
  - MEGII, Babar, LHCb, Belle-II

- Interest in future projects
  - future $\mu \to e\gamma$ searches
  - LHCb Upgrade-II
  - τLFV
  - Possible Belle-II upgrades

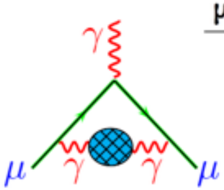
Summary of expertise
- gas detectors
- electronics
- reconstruction algorithms
- data analysis

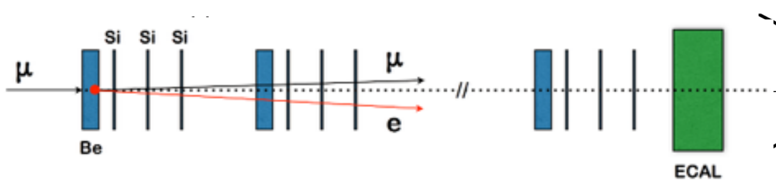
Crucial the INFN technical support for both the present and the future

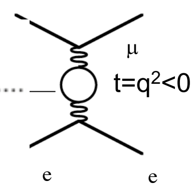
Backup

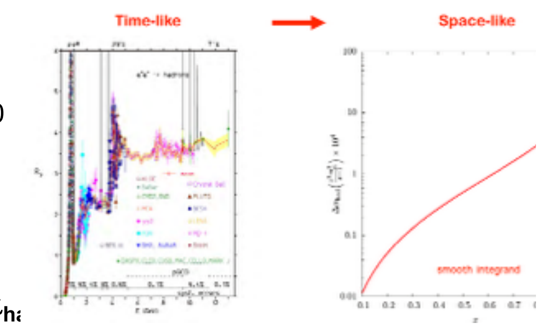
MuonE

- Contributo adronico al g–2 generalmente ricavato utilizzando i dati dello scattering
  - $e^+e^- \rightarrow$ had (time-like data – KLOE…)
  - L'integrale a bassa energia dà contributo dominante all'incertezza
- Si può calcolare indipendentemente il contributo adronico LO utilizzando dati space-like (scattering elastico $\mu e \rightarrow \mu e$)
  - fascio di muoni da 150 GeV su bersaglio di Be al CERN
    - primo test beam 2017, secondo test beam in corso al CERN
    - run 2021-2024 con costruzione nel 2020-2021 (LoI expected in 2019)
    - possibile raggiungere un'incertezza di 0.3% (stat, syst. comp.)
  - rimuovere la componente QED ⇒ sforzo teorico in corso (full NNLO MC per μe scattering)
  - rivelatori utilizzano tecnologia attuale (no R&D). 60 tracking stations + Calo = ~50m
  - M2 beam line @North Area





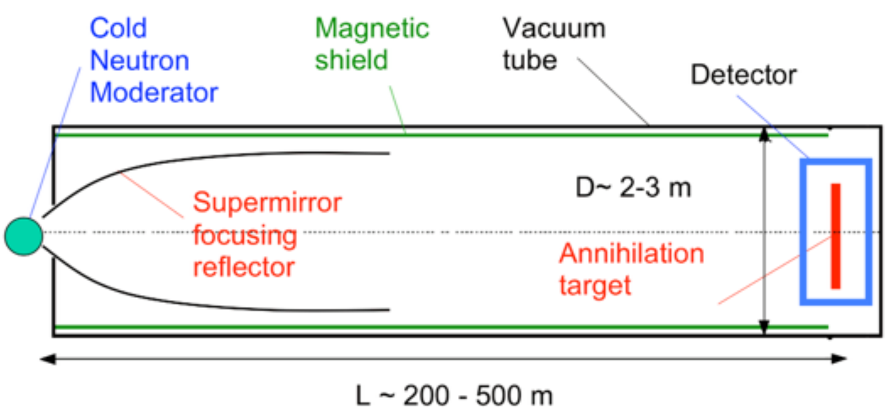


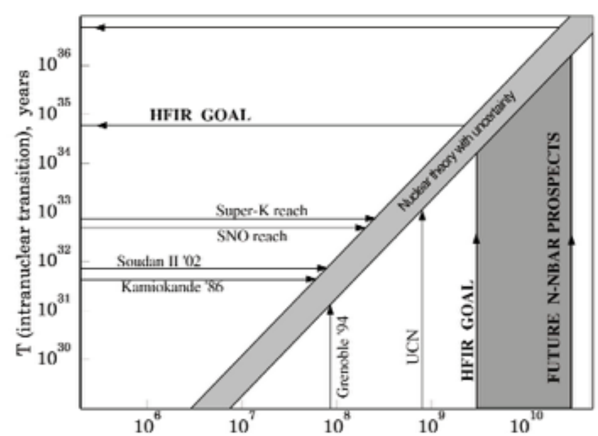


$$\left|\frac{\alpha(t)}{\alpha_0}\right|^2 = \left|\frac{1}{1-\Delta\alpha(t)}\right|^2 \quad \Delta\alpha = \Delta\alpha_{lep} + \Delta\alpha_{ha}$$

n-nbar oscillation

- In questo contesto l'ultima cosa da considerare è un esperimento per la rivelazione delle oscillazioni neutrone-antineutrone
- Costo elevato a causa dell'infrastruttura (screening, neutron reflectors) ~100M€
- beam of neutron + far detector where the nbar annihilates
- limit ILL in Grenoble $\tau > 8.6 \times 10^7$ sec.
- Spallation target to improve the limit by 2 orders of magnitude ⇒ optics technology developed for material science experiments
- n-nbar exp at ESS (European Spallation Source, Lund, Sweden) Y. Kamishkov et al.
- use the know-how of the 1991 exp + implementing a new idea of cold neutron focussing from the large aperture source. Improvement by a factor of 100 by using mirrors from swiss neutronics





Higgs

How can we learn more?

First two generations;
down quark 3^{dr} generation

Meson mixing (Bs);
Rare B decays experiments

Higgs flavor violation

up type and lepton 3^{dr} generation

Higgs rare processes

$t \to c$, $t \to u$

$\tau \to \mu$, $\tau \to e$

High energy machines

Higgs & gauge boson CP violation

High energy machines

&

e^+e^- machines

CPV in Higgs-gauge boson couplings

CPV in Higgs-fermion couplings

CPV in triple-gauge boson couplings

Electron EDM experiments