

\* FCC-injectors WG: Physics  
Opportunities with FCC  
Injectors.

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*From discussions with many people, including:  
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# Introduction

The main problem we have today in HEP is that **we know** there is **physics beyond the SM** (dark matter (energy), neutrino oscillations, matter anti-matter asymmetry) but **we don't know** at what **energy scale(s)**.

Ideally, we would like to have **an indication** of this(these) energy scale(s) **from experiment**. If it turns out that the energy **of the LHC is not enough**, the only chance is through “**relevant**” **precision measurements** → **INTENSITY FRONTIER**.

Using the **LHC data**, **ATLAS** and **CMS** will measure with  **$O(10\%)$  precision** or better the **Yukawa couplings of the Higgs boson** and will have a look at other interesting precision measurements like **rare top decays**. **LHCb** will improve the measurements of **FCNC in b and c decays**, and will overconstrain **the measurements of the only phase in the CKM matrix**.

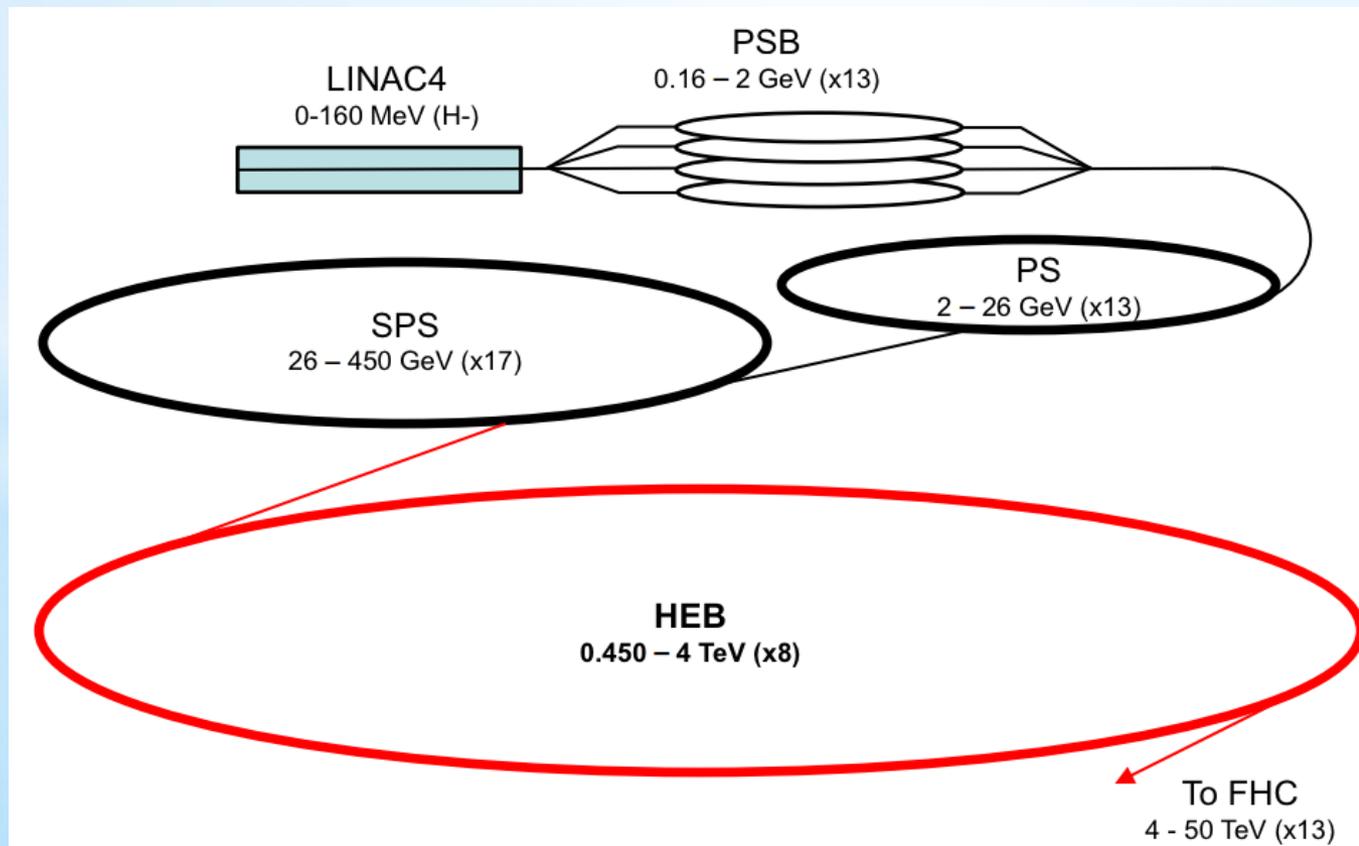
**NA62** and **KOTO** will be looking at **FCNC in s decays**. At **PSI, JPARC** and **Fermilab** interesting new results on **muon LFV decays** will be available in the next decade.

# Introduction

Are there other physics opportunities at CERN that:

- a) are sensitive probes of the scale of NP?
- b) cannot be done elsewhere or can be done significantly better at CERN?

The idea is to use the existing **FCC forum**, to bring together **accelerator, experimental** and **theoretical physicists** to discuss these issues. If we don't discuss these opportunities at this stage, we risk to have the design of the **FCC injectors not flexible enough!**



# Introduction

As our boss likes to say: “**physics first**”... it would be good if we can identify **few opportunities** that satisfy conditions “a” and “b” and they are discussed in an **open forum**, involving **accelerator, experimental** and **theoretical** physicists.

Then, we should check the **detector and accelerator requirements** and evaluate it's **feasibility and compatibility** with the **FCC** project. At this stage, there are many options open. From the “obvious” extraction of beams from the injectors to perform fixed target experiments, to use the injectors (like HEB) in collider mode, or to include polarized protons in the injection chain, or...

If **enough interest** and **opportunities** are identified in the coming months, we could organize a **workshop** (beg. of 2015?) to **discuss** them, and decide how to **document** the findings.

Yes, being **imaginative and ambitious is risky**, may provide ideas that are not going to be feasible... but nothing within the FCC project seems to me not to be in this class!

# Introduction

You may ask, **why another workshop** on the intensity frontier options?

Didn't we had one at CERN in 2009 organized by the CERN management?



Well, yes, but at that time the **LHC was just coming online** and a large fraction of the community was very much focused to find evidence of NP (including the Higgs) at the LHC. **After LHC RUN2** the **circumstances may not be the same**, and the **need for diversification** may be better appreciated. Moreover, in the FCC context, we do have one more injector to consider (HEB).

FCC studies time scale is to be able to be considered as an option for the next **European Strategy Update (2018?)**. By then it would be good to have also a view of the **complementary physics opportunities** offered by the CERN injectors.

*In the following slides, I show few examples we have been discussing. It just shows my personal bias, and by no means are exhaustive.*

# Few examples: Nucleon EDMs

Why the SM does not include **CP violation in the strong sector**? One idea is the spontaneously broken **Peccei-Quinn** symmetry, but where's the **axion**?

Within the SM  $d_{\text{nucl}}^{\text{SM}} \sim < 10^{-31}$  e cm. An observation of a non-zero **EDM** in the foreseeable future will be a **clear indication of NP** (in the case of nucleons, possibly **CP violation in the strong interactions**).

At least two groups, at **USA** and **Germany**, are developing plans for storage rings with  $10^{10}$  p/sec and **>80% polarization** with a reach of **proton-EDM  $10^{-29}$  e cm**.

Building such storage rings (R~40m, 10MV/m) and provide high intensity low energy polarized proton beams is certainly a **challenge**.

**Synergy with FCC studies using polarized protons!**

Category	Limit (e cm)	Experiment	Standard Model Value (e cm)
Electron	$1.0 \times 10^{-27}$ (90% C.L.)	YbF molecules in a beam [10]	$10^{-38}$
Muon	$1.9 \times 10^{-19}$ (95% C.L.)	Muon storage ring [11]	$10^{-35}$
Neutron	$2.9 \times 10^{-26}$ (90% C.L.)	Ultracold neutrons in a bottle [12]	$10^{-31}$
Proton	$[7.9 \times 10^{-25}]$	Inferred from $^{199}\text{Hg}$ [13]	$10^{-31}$
Nucleus	$3.1 \times 10^{-29}$ (95% C.L.)	$^{199}\text{Hg}$ atoms in a vapor cell [13]	$10^{-33}$

Recent study in the context of **Project-X** (including **stochastic cooling**) claims:

Table V-4: The required beam parameter values and the projected sensitivities

Particle	Beam intensity, polarization, $NP^2$	Horizontal, vertical emittance 95%, normalized [mm-mrad], dp/p	Momentum [GeV/c]	Projected Sensitivity [e cm]
Protons	$4 \times 10^{10}$ , > 80%	2, 6, $2 \times 10^{-4}$ rms	0.7	$10^{-29}$ , $10^{-30}$
Deuterons	$2 \times 10^{11}$ , > 80%	3, 10, $10^{-3}$	1	$10^{-29}$
$^3\text{He}$	TBD, > 80%	TBD	TBD	$< 10^{-28}$
Muons	$NP^2 = 5 \times 10^{16}$ total	800, 800, 2% max	<b>3, 1</b>	$10^{-24}$

# Few examples: CLFV decays.

CLFV is an extremely interesting physics case that may help to explain the mechanism by which neutrinos are massive!

It is **difficult to do significantly better** than the proposed experiments at JPARC and Fermilab in  $\mu \rightarrow e\gamma$  at CERN. It's clear that EDMs and Muon LFV programs are not unique for CERN facilities.

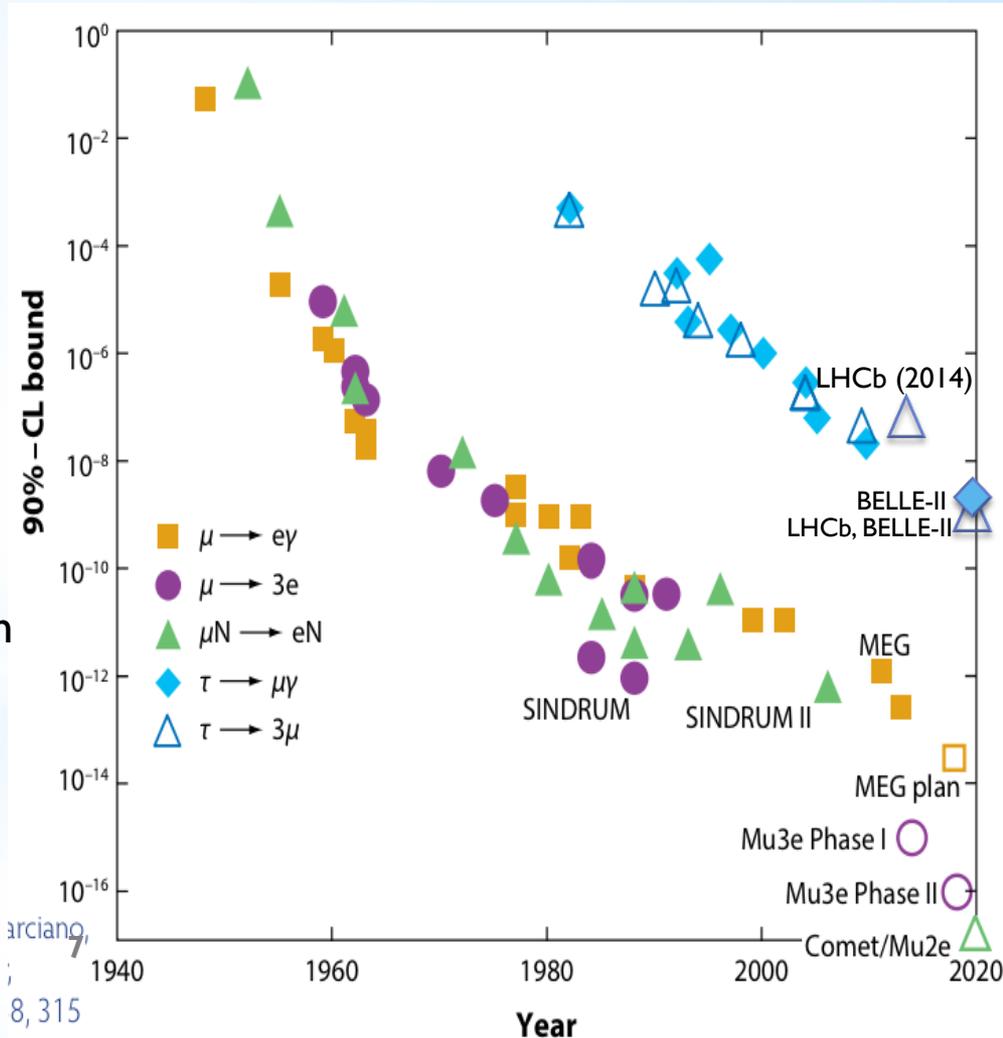
*Global considerations.*

In principle  $\tau$  are more sensitive than  $\mu$  since mass typically decreases GIM suppression, ( $>500$ ). However, rates at  $e^+e^-$  B-factories are  $\sim 2 \times 10^9$   $\tau$  /ab.

The best limits using  $\sim 1.4 \times 10^9$   $\tau$  events at the B-factories. Belle-II expects to collect  $50 \text{ ab}^{-1}$ , and improve by factor 10 the sensitivity.

However, **at HE pp collisions (LHC) taus are copiously produced** (mainly from charm decays,  $D_s \rightarrow \tau \nu$ ).

Recently, **LHCb** has reached **similar sensitivities** for  $\text{BR}(\tau \rightarrow \mu \mu \mu)$  than B-factories using  $3 \text{ fb}^{-1}$ , i.e.  $2 \times 10^{11}$   $\tau$  produced.



# LFV tau decays using proton beams.

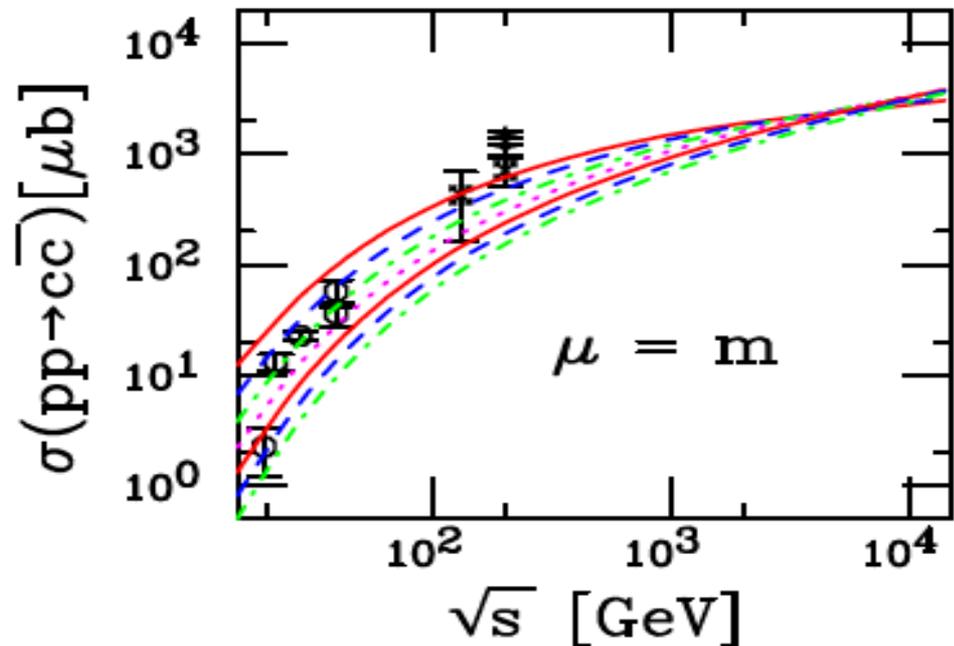
LHCb plans to collect  $50\text{fb}^{-1}$  at 14 TeV and accumulate  $\sim 8 \times 10^{12}$   $\tau$  produced  
→ similar sensitivity than BELLE-II.

However, in the **HL-LHC** ( $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ ) regime expect  $\sim 1.6 \times 10^{14}$   $\tau$  /  $\text{ab}^{-1}$  produced.  
Moreover, there are no showstoppers to go beyond in luminosity ( $> 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ ). Notice that even a  $e^+e^-$   $\tau$  / charm factory has only x3 larger cross-section than a B-factory.

If an experiment can have similar (or better) acceptance than LHCb and profit from the maximum luminosity, expect  $\text{BR}(\tau \rightarrow \mu \mu \mu) < 10^{-10}$ , or even  $10^{-11}$  depending on how the bkg scales. Also a new experiment could look at  $\text{BR}(\tau \rightarrow \mu \gamma)$  using **converted photons**.

**Energy** of the collisions **helps**. Going down to 0.03 TeV pp collisions (SPS fixed target), is  $\sim 50$  lower cc cross-section.

**Detector resolution** is crucial in hadronic environment to control backgrounds.

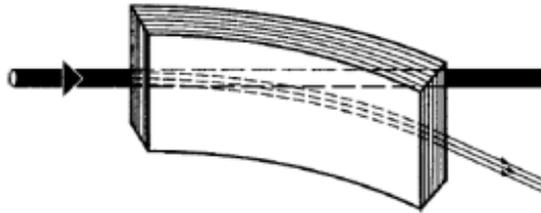


# Other possibilities.

As we have discussed, if we have **high intensity proton beams** at energies  $\sim 100$  GeV, we have an enormous source of **charm** (hence of **taus**). But also and enormous production of **beauty** and **strange** mesons.

For some time there have been discussions to use beams from the LHC extracted by **bent a crystal** (running in parallel to the LHC, **AFTER@LHC**) or extracting protons from HEB. This could provide protons on target collisions of  $\sim 115$  GeV.

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



**Are there clean measurements with strange, charm and beauty decays that could give information on the scale of NP, and be performed with such facility?**

**Are there specific NP searches that could benefit from these beam lines? Dark Matter, Dark Photons/HNL, ...**

**Not to forget, the design of the FCC detectors requires to setup test-beam lines able to provide high energy/intensity beams.**

## FCC WG on experiments with the CERN injectors

chaired by Frederic Teubert (CERN), Gino Isidori (Istituto Nazionale Fisica Nucleare (IT)), Brennan Goddard (CERN)

Monday, 29 September 2014 from **09:00** to **12:30** (Europe/Zurich)  
at **CERN ( 4-3-006 - TH Conference Room )**

**Description** This is the first meeting of the FCC Working Group studying physics opportunities using the CERN injectors, including the option of LHC as High Energy Booster (HEB) injector of FCC. We would like to use these WG meetings to prepare an open workshop by the end of 2014, where the accelerator, experimental and theoretical communities can discuss interesting opportunities that complement the HL-LHC and FCC physics program and diversify the search for New Physics.

At this meeting we plan to have an initial discussion of the injectors upgrade plans (including a possible design of a very high luminosity IR at HEB), and of possible experiments such as Lepton Flavour Violation in tau decays using the CERN injectors, opportunities with Kaon decays. We invite the participants to put forward other ideas and topics for discussion, including a first definition of future needs for test beams. A theory talk will review the interest of this physics programme.

If you wish to contribute with a presentation, please inform the organizers.

To join the mailing list for communications on the activities of the WG, go to

<https://e-groups.cern.ch/e-groups/>  
search for the "fcc-experiments-physinj" e-group, and subscribe.