* Introduction: Physics Opportunities with FCC Injectors.

Frederic Teubert

CERN, PH Department

From discussions with many people, including: Augusto Ceccucci, Fabiola Gianotti, Brennan Goddard, Andrei Golutvin, Gino Isidori, Tatsuya Nakada and Michelangelo Mangano.

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%) or better precision 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.

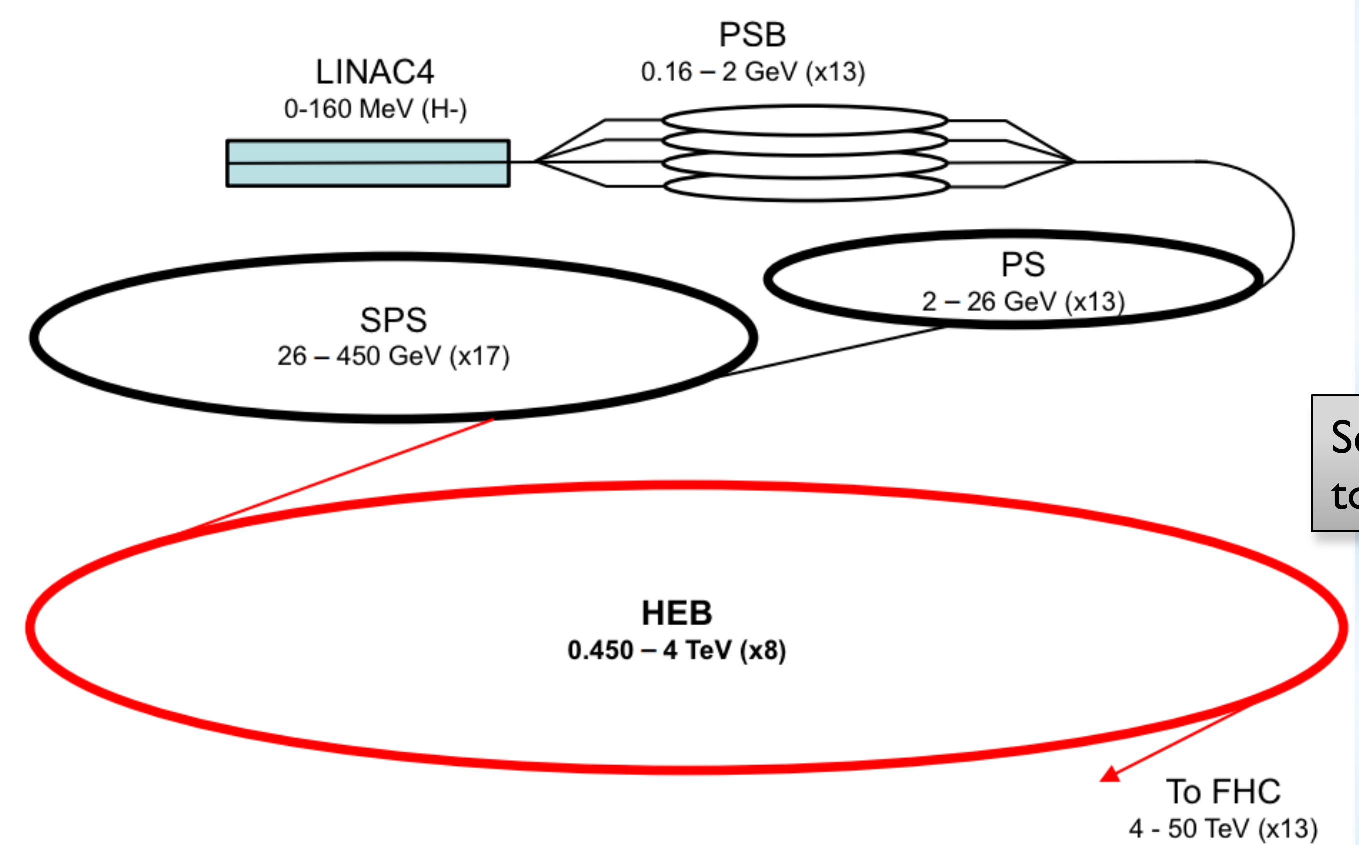
Introduction

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!**



See Brennan's talk today for details.

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…

See Brennan's talk for what kind of questions we need to answer.

If enough interest and opportunities are identified in the coming months, we could organize a workshop (end of 2014?) 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_{nucl}^{SM}~<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.**

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

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

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

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	4×10^{10}, $>80\%$	2, 6, 2×10^{-4} rms	0.7	10^{-29}, 10^{-30}
Deuterons	2×10^{11}, $>80\%$	3, 10, 10^{-3}	1	10^{-29}
^{3}He	TBD, $>80\%$	TBD	TBD	$<10^{-28}$
Muons	$NP^2=5\times10^{16}$ total	800, 800 , 2% max	3,1	10^{-24}

Synergy with FCC studies using polarized protons!

Few examples: CLFV decays.

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

See Gino's talk today for motivation.

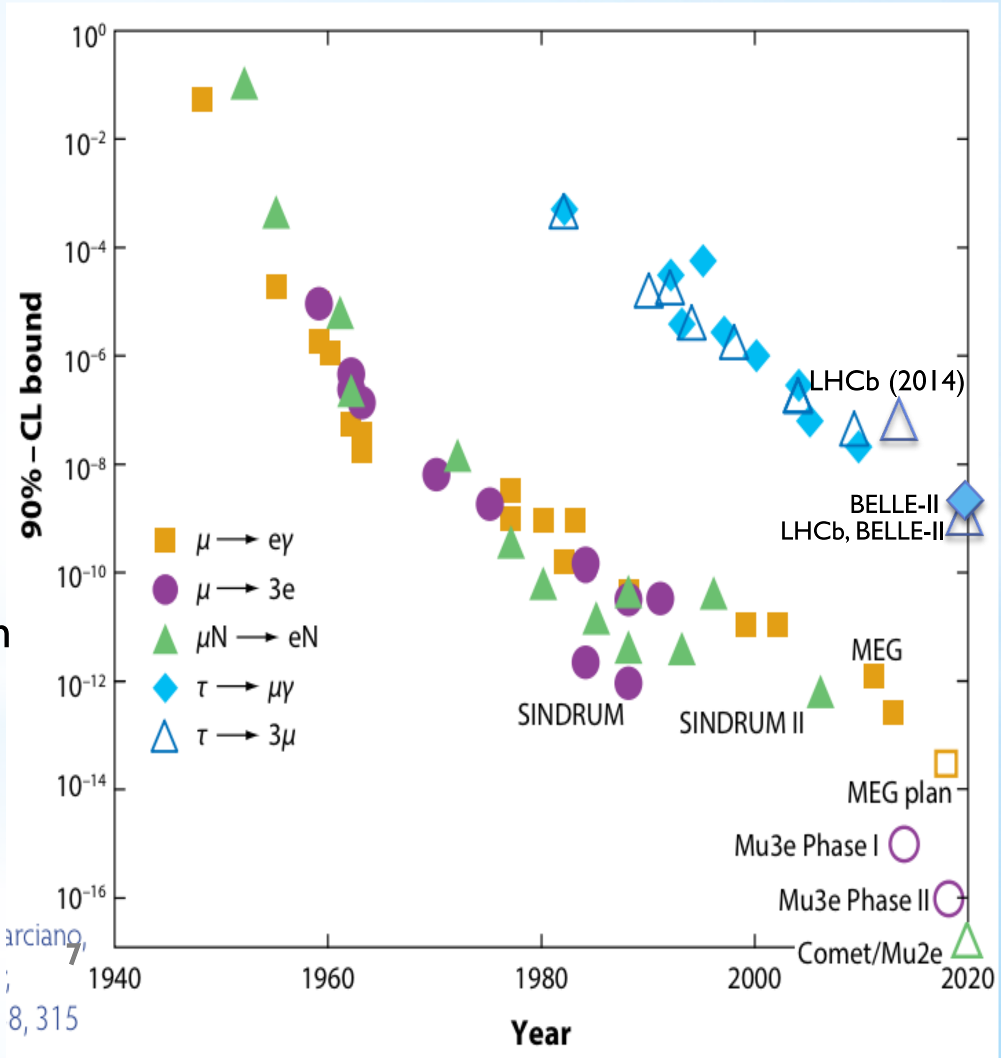
It is difficult to do significantly better than the proposed experiments at JPARC and Fermilab in $\mu \rightarrow eN$ at CERN. *It's clear that EDMs and Muon LFV programs are not unique for CERN facilities. Global considerations.*

In principle τ are more sensitive than μ since mass typically decreases GIM suppression, (>500). However, rates at e^+e^- B-factories are ~2×10^9 τ/ab.

The best limits using ~1.4×10^9 τ events at the B-factories. Belle-II expects to collect $50 ab^{-1}$, 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 BR($\tau \rightarrow \mu\mu\mu$) than B-factories using $3fb^{-1}$, i.e. 2×10^{11} τ produced.



LFV tau decays using proton beams.

LHCb plans to collect $50 fb^{-1}$ at 14 TeV and accumulate ~$8x10^{12}$ τ produced
→similar sensitivity than BELLE-II.

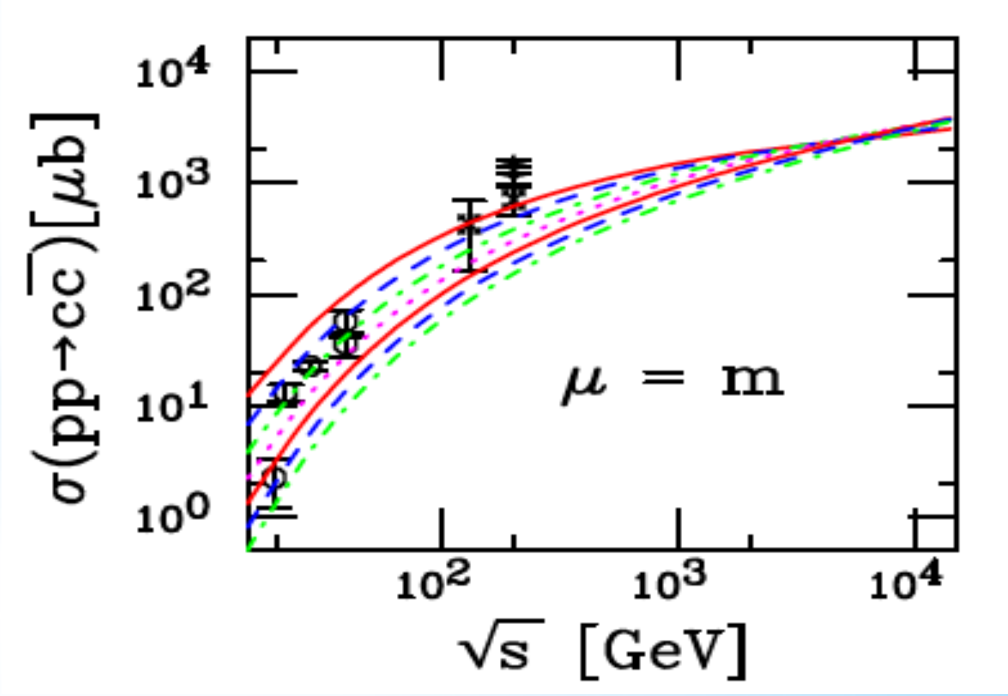
However, in the HL-LHC ($5x10^{34}$ cm^{-2} s^{-1}) regime expect ~$1.6x10^{14}$ τ $/ab^{-1}$ produced. Moreover, there are no showstoppers to go beyond in luminosity **($>10^{35}$ cm^{-2} s^{-1})**. Notice that even a e^+e^- τ /charm factory has only x3 larger cross-section than a B-factory.

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

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

Detector resolution is crucial in hadronic environment to control backgrounds.

See Marcin's talk today for more details.



Other possibilities.

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

See Matt's talk today for more details on Kaon decays.

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

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, …

Monday, 29 September 2014

09:00 - 09:20	Introduction *20'* Speaker: Frederic Teubert (CERN)
09:20 - 09:50	Injectors Plans *30'* Speaker: Dr. Brennan Goddard (CERN)
09:50 - 10:20	Theory Overview *30'* Speaker: Gino Isidori (Istituto Nazionale Fisica Nucleare (IT))
10:20 - 10:40	Coffee break
10:40 - 11:10	LFV tau decays *30'* Speaker: Marcin Chrzaszcz (University of Zurich (CH), Polish Academy of Sciences (PL))
11:10 - 11:40	Kaon decays *30'* Speaker: Matthew Moulson (Istituto Nazionale Fisica Nucleare (IT))