ESPP and intensity frontier of particle physics

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Triumph of the SM in particle physics

- The Standard Model in now **complete**: the last particle - Higgs boson, predicted by the SM, has been found
- **No significant deviations** from the SM have been observed
- With experimental values of the top quark and Higgs boson masses, the SM is a **self-consistent effective field theory** all the way up to the quantum gravity Planck scale $M_P \sim 10^{19}$ GeV.

However, the SM does not explain

- origin of neutrino masses,
- dark matter,
- baryon asymmetry of the Universe.

Unfortunately, these facts do not tell us anything about the scale of new physics. Indeed, all these facts can be explained, for example, by Majorana fermions with masses from a fraction of eV to $\sim 10^{15}$ GeV .

Theory guidance which has led to the discovery of the Higgs boson is over

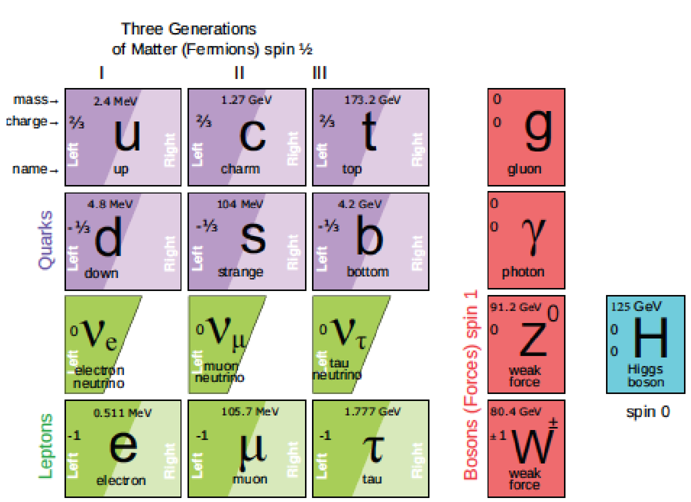
- "Naturalness": absence of quadratic divergencies in the Higgs mass. Suggestions: low energy SUSY, composite Higgs boson, large extra dimensions, …

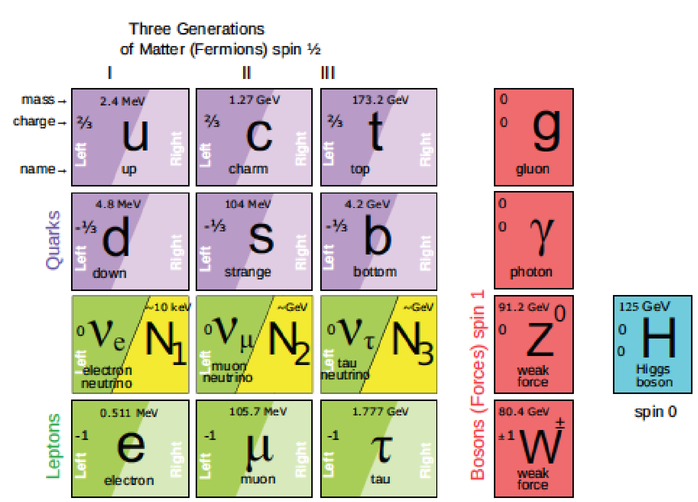
All require new physics right above the Fermi scale. This NP was expected to show up at the LHC and even earlier, but it did not. Pursuing high energy and precision frontiers?

- "Simplicity": no new particles with masses above the Fermi scale, all drawbacks of the SM are explained by feebly interacting hidden particles - FIPS (HNL - heavy neutral leptons, axion-like particles, different dark sectors, dark photons, scalars, portal interactions, etc.)

Requires dedicated searches of feebly interacting particles. Pursuing high intensity frontier?

Example of a theory solving all observational problems: νMSM





Role of the Higgs boson: break the symmetry and inflate the Universe

Role of N1 with mass which can be as small as few keV: dark matter.

Role of N2 and N3 with masses which can be as small as 100 MeV : "give" masses to neutrinos and produce baryon asymmetry of the Universe

Different frontiers of high energy physics

- Precision frontier. The **indirect** search for New Physics: measurements of possible deviations from the SM at any energy scale in high-precision experiments (e.g. LHCb, NA62, …)

- Energy frontier. The **direct** search for New Physics: observation of new phenomena at high energies, such as the production of new types of massive particles (e.g. ATLAS, CMS, …).

- Intensity frontier. The **direct** search for New Physics: looking for feebly interacting, relatively light particles using high intensity beams (e.g. SHiP, …)

Of course, this division is not strict and there are many overlaps: sensitivity domains of ATLAS/CMS and of Intensity Frontier experiments are complementary and cover different parts of the parameter space.

Intensity frontier of high energy physics

Experimental challenges of the hidden particle searches

Hidden particle production and decays are highly suppressed => dedicated experiments are needed.

- New generic purpose experiments to search for all sorts of relatively light dark sector particles (dark photons, hidden scalars, etc).
- Existing experiments in the quest for hidden sector particles.

Searches for dark sectors

NA62 P326

SHiP
Search for Hidden Particles

DARKLIGHT

Belle II

CMS

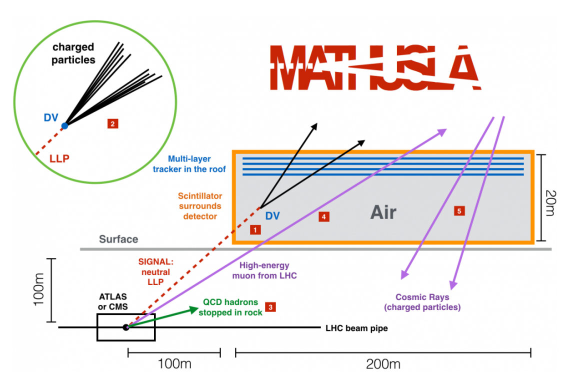
T2K

LHCb

DUNE
DEEP UNDERGROUND NEUTRINO EXPERIMENT

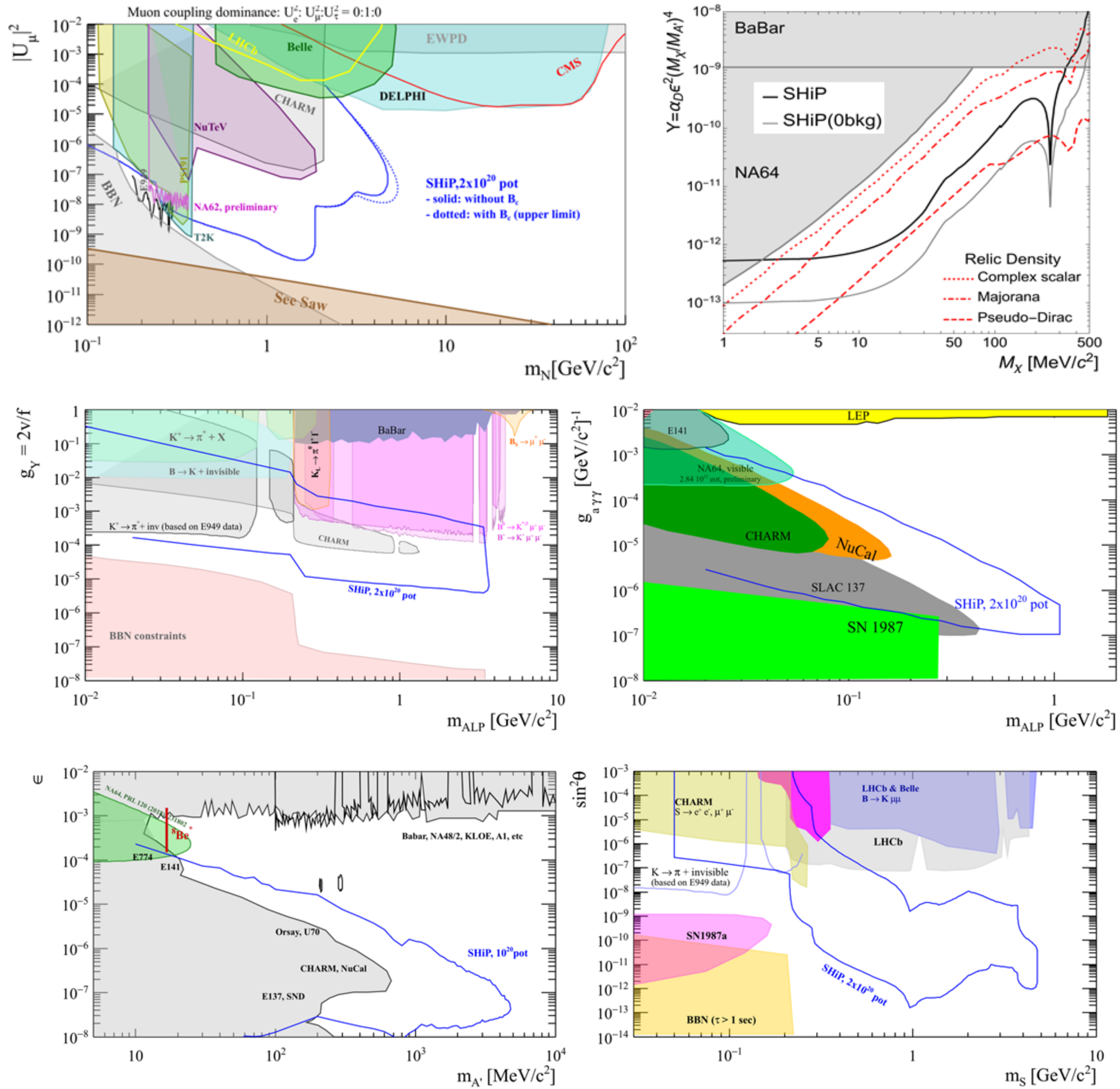
ATLAS EXPERIMENT

NA64 Search for dark sectors in missing energy events



FCC hh ee he

FASER



Muon coupling dominance: $U_e^2 : U_\mu^2 : U_\tau^2 = 0:1:0$
$|U_\mu|^2$
EWPD
LHCb
Belle
CMS
DELPHI
CHARM
NuTeV
PS191
E949
BBN
NA62, preliminary
T2K
SHiP, 2×10^{20} pot
- solid: without B_c
- dotted: with B_c (upper limit)
See Saw
m_N [GeV/c^2]
$Y = \alpha_D \epsilon^2 (M_\chi/M_{A'})^4$
BaBar
NA64
SHiP
SHiP(0bkg)
Relic Density
Complex scalar
Majorana
Pseudo-Dirac
M_χ [MeV/c^2]
$g_Y = 2v/f$
$K^+ \to \pi^+ + X$
BaBar
$B \to K$ + invisible
$K_L \to \pi^0 \ell^+ \ell^-$
$B_s \to \mu^+ \mu^-$
$K^+ \to \pi^+$ + inv (based on E949 data)
CHARM
$B^0 \to K^{*0} \mu^+ \mu^-$
$B^+ \to K^+ \mu^+ \mu^-$
SHiP, 2×10^{20} pot
BBN constraints
m_{ALP} [GeV/c^2]
$g_{a\gamma\gamma}$ [GeV/c^2]$^{-1}$
LEP
E141
NA64, visible
CHARM
NuCal
SLAC 137
SHiP, 2×10^{20} pot
SN 1987
m_{ALP} [GeV/c^2]
ϵ
NA64, PRL 120 (2018) 231802
^{8}Be
E774
E141
Babar, NA48/2, KLOE, A1, etc
Orsay, U70
SHiP, 10^{20} pot
CHARM, NuCal
E137, SND
$m_{A'}$ [MeV/c^2]
$\sin^2\theta$
CHARM
$S \to e^+ e^-, \mu^+ \mu^-$
LHCb & Belle
$B \to K \mu\mu$
LHCb
$K \to \pi$ + invisible
(based on E949 data)
SN1987a
SHiP, 2×10^{20} pot
BBN ($\tau > 1$ sec)
m_S [GeV/c^2]

Review of the current status: conference which was supposed to take place at CERN, but now will be virtual. More than 400 registered participants.

Intensity frontier of high energy physics

Several community papers were written, for example:

Europe:

- “A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case”, 2016, 515 citations
- Physics Briefing Book, ESPP, 2019

USA:

- “Fundamental Physics at the Intensity Frontier”, 2012, 367 citations
- “Working Group Report: New Light Weakly Coupled Particles”, 2013, 525 citations

CERN: Physics beyond colliders study group was created in 2016

- “Physics Beyond Colliders at CERN: Beyond the Standard Model Working Group Report”, 2019, 121 citations

High intensity frontier attracts a lot of attention:

- SHiP experiment (not approved) has been mentioned in 334 articles, which were cited 7822 times until today.

Interesting to compare with other CERN experiments

- LHCb experiment has been mentioned in 99 articles written in 1998 (year of approval) and before. They were cited 1187 times until today.

- ATLAS experiment has been mentioned in 120 articles written in 1996 (year of approval) and before. They were cited 2686 times until today.

- CMS experiment has been mentioned in 98 articles written in 1996 (year of approval) and before. They were cited 3130 times until today.

- SHiP > ATLAS + CMS + LHCb at the similar stage of career in these metrics!

Comparison of high intensity frontier and high energy frontier using SHiP/BDF (possible data taking in this decade) and FCC (possible data taking in 20-40 years):

- SHiP experiment has been mentioned in 334 articles, which were cited 7822 times until today.
- FCC (ee and hh) has been mentioned in 2319 articles which were cited 31403 times until today

$$\frac{\text{SHiP} \quad \text{articles}}{\text{FCC} \quad \text{articles}} = \frac{1}{7}$$

Accounting for the cost, SHiP/BDF is 14 times better investment than FCC 🙂

SHiP + BDF = 250 Millions CHF; FCC= 25 Billions CHF

$$\frac{\text{SHiP} \quad \text{articles/cost}}{\text{FCC} \quad \text{articles/cost}} = 14$$

- Of course, all these numbers are not intended to argue that one experiment is better or worse than another.
- They just meant to provide a digital evidence that the intensity frontier is a mature direction of research supported very well by the physics community.
- What is most important, of course, is its strong physics case.

Swiss participation in high intensity frontier

Nodes involved in high intensity frontier (theory and experiment): Geneva, Lausanne, Bern, Zurich, Basel

Swiss input document to ESPP reflects this interest:

“Exploiting high intensity facilities at national laboratories and CERN “

“Similarly, the CERN accelerator complex can provide unique opportunities with a modest investment. CERN should explore the possibility of constructing well motivated non-collider facilities that are unique to CERN. The Swiss community considers a beam dump facility with the SPS beam particularly interesting. The SPS provides a high intensity high energy proton beam which can be used in a beam dump mode, a unique place to look for rare phenomena in the low mass range. The SHiP experiment could be a possible user of such a facility. “

ESPP deliberation document, June 2020

“A dedicated Physics Beyond Colliders study group was set up at CERN to explore the opportunities offered by the CERN accelerator complex and infrastructure to gain new insights into some of the outstanding questions in particle physics through projects complementary to high-energy colliders and other initiatives in the world. This generated a lot of interest and became the de facto focal point for new research initiatives centred not only on the potential of the CERN facilities but also other facilities available throughout Europe in the National Laboratories and research institutes. Many of the proposals for new experiments at CERN are on a scale such that they could be considered for approval in the usual manner by the scientific committees and the Research Board. Among the proposals for larger-scale new facilities investigated within the Physics Beyond Colliders study, the Beam Dump Facility at the SPS emerged as one of the frontrunners. However, such a project would be difficult to resource within the CERN budget, considering the other recommendations of this Strategy.”

Why high intensity frontier is not a priority in ESPP?

This contradicts to:

- HEP community interest
- Granada outcome
- Swiss input to ESPP
- to what Director General of CERN said several times, e.g. on June 29, 2020:

- ❑ Precise measurements and exclusion of unfounded theoretical scenarios are as crucial as discoveries to make progress and redirect our theoretical thoughts(*) and experimental exploration towards the most promising directions.

  (*) "*When theorists are more confused, it's time for more, not less, experiments*", Nima Arkani-Hamed.

I thought it will be easy to find out why intensity frontier is not a priority…

"Fundamentally an open, inclusive and science-driven process, this update of the European Strategy for Particle Physics got under way in September 2018 when the CERN Council established the independent European Strategy Group (ESG) to coordinate the process. In a truly collaborative initiative, by the end of 2018 the particle physics community had submitted 160 contributions encompassing the worldwide particle-physics landscape and developments in related fields. In May 2019, the community came together and discussed the potential merits and challenges of the submitted proposals, in an open symposium in Granada, Spain. The inputs were distilled into the 250-page Physics Briefing book, an objective scientific summary published in September 2019, which formed the basis for the ensuing discussions. "

But this happened to be not the case:

- All the documents were kept top secret from January 2020 until the strategy documents release in June 19, 2020.

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- No explanations why intensity frontier was not supported were provided.

- The community had no chances and time to react.

I believe, the importance and the physics community support of the intensity frontier have been underestimated

Proposal 1

- Request the ESPP to modify the deliberation document. Minimum action change:

"A dedicated Physics Beyond Colliders study group was set up at CERN to explore the opportunities offered by the CERN accelerator complex and infrastructure to gain new insights into some of the outstanding questions in particle physics through projects complementary to high-energy colliders and other initiatives in the world. This generated a lot of interest and became the de facto focal point for new research initiatives centred not only on the potential of the CERN facilities but also other facilities available throughout Europe in the National Laboratories and research institutes. Many of the proposals for new experiments at CERN are on a scale such that they could be considered for approval in the usual manner by the scientific committees and the Research Board. Among the proposals for larger-scale new facilities investigated within the Physics Beyond Colliders study, the Beam Dump Facility at the SPS emerged as one of the frontrunners. ~~However, such a project would be difficult to resource within the CERN budget, considering the other recommendations of this Strategy~~. This initiative should be strongly encouraged."

Proposal 2

- Request the ESPP to modify the main document, by inserting this paragraph from deliberation document:

"A dedicated Physics Beyond Colliders study group was set up at CERN to explore the opportunities offered by the CERN accelerator complex and infrastructure to gain new insights into some of the outstanding questions in particle physics through projects complementary to high-energy colliders and other initiatives in the world. This generated a lot of interest and became the de facto focal point for new research initiatives centred not only on the potential of the CERN facilities but also other facilities available throughout Europe in the National Laboratories and research institutes. Many of the proposals for new experiments at CERN are on a scale such that they could be considered for approval in the usual manner by the scientific committees and the Research Board. Among the proposals for larger-scale new facilities investigated within the Physics Beyond Colliders study, the Beam Dump Facility at the SPS emerged as one of the frontrunners. This initiative should be strongly encouraged."

Proposal 3

- Propose to the ESPP to modify the procedure for the next strategy update, making the draft strategy document public and allowing the physics community to provide a feedback.