

## Forward Physics Facility at the FCC.

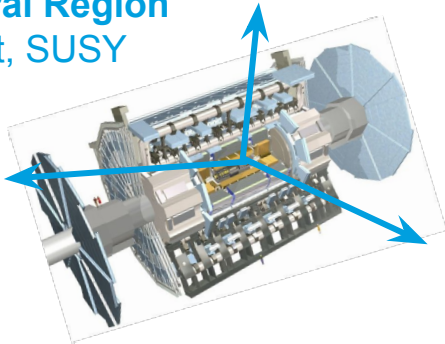
Felix Kling  
FCC BSM Physics Programme Workshop  
06/03/2022



# One Slide of Motivation.

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**Central Region**  
H, t, SUSY

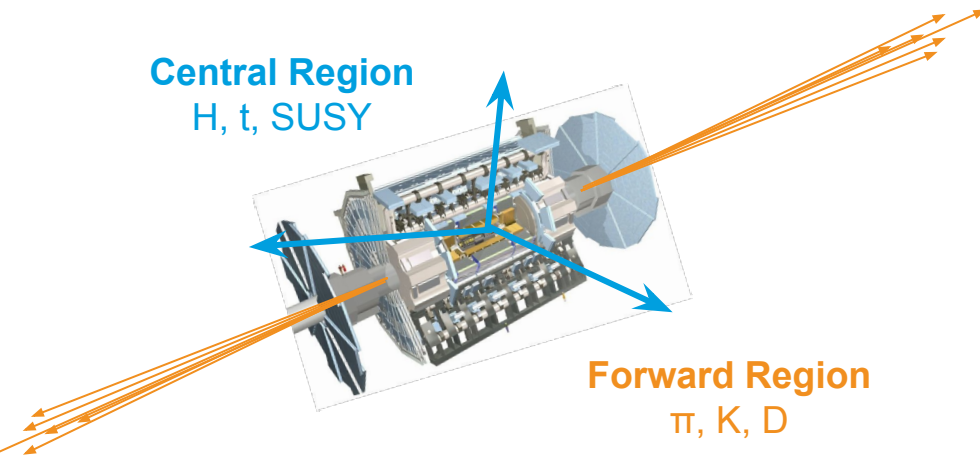


# One Slide of Motivation.

The LHC produces an **intense** and strongly **collimated** beam of highly **energetic** particles in the forward direction.

$10^{17}$   $\pi^0$ ,  $10^{16}$   $\eta$ ,  $10^{15}$  D,  $10^{13}$  B within 1 mrad of beam

**Can we do something with that?**

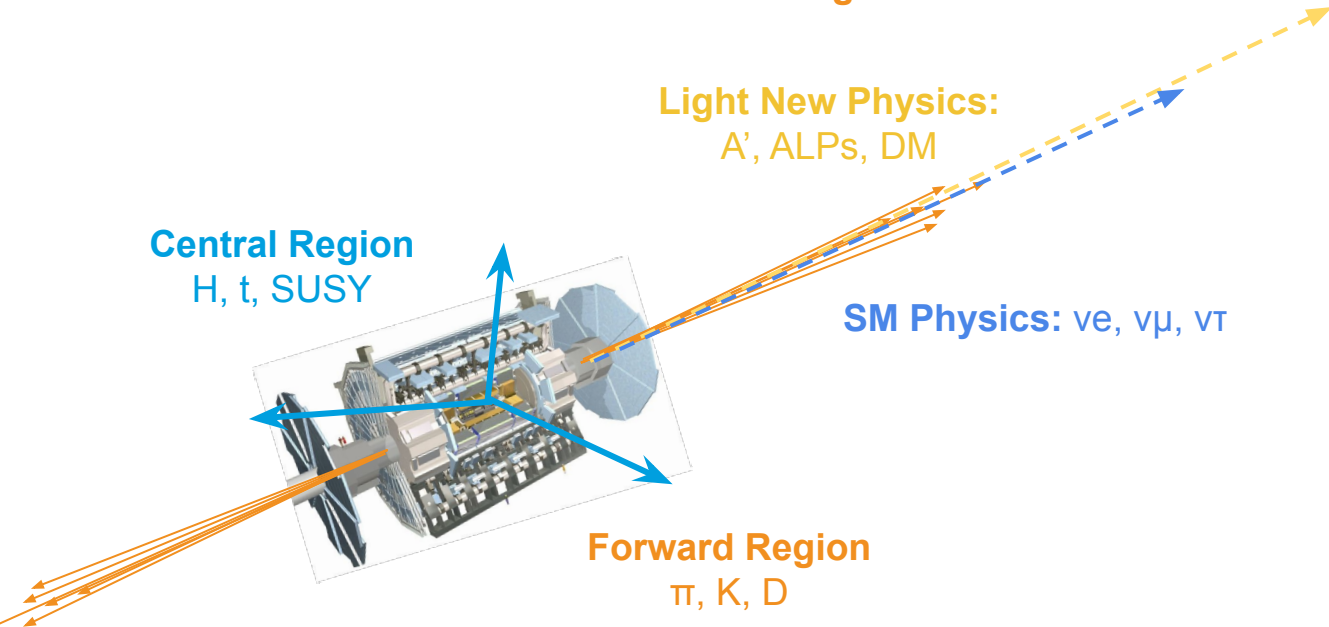


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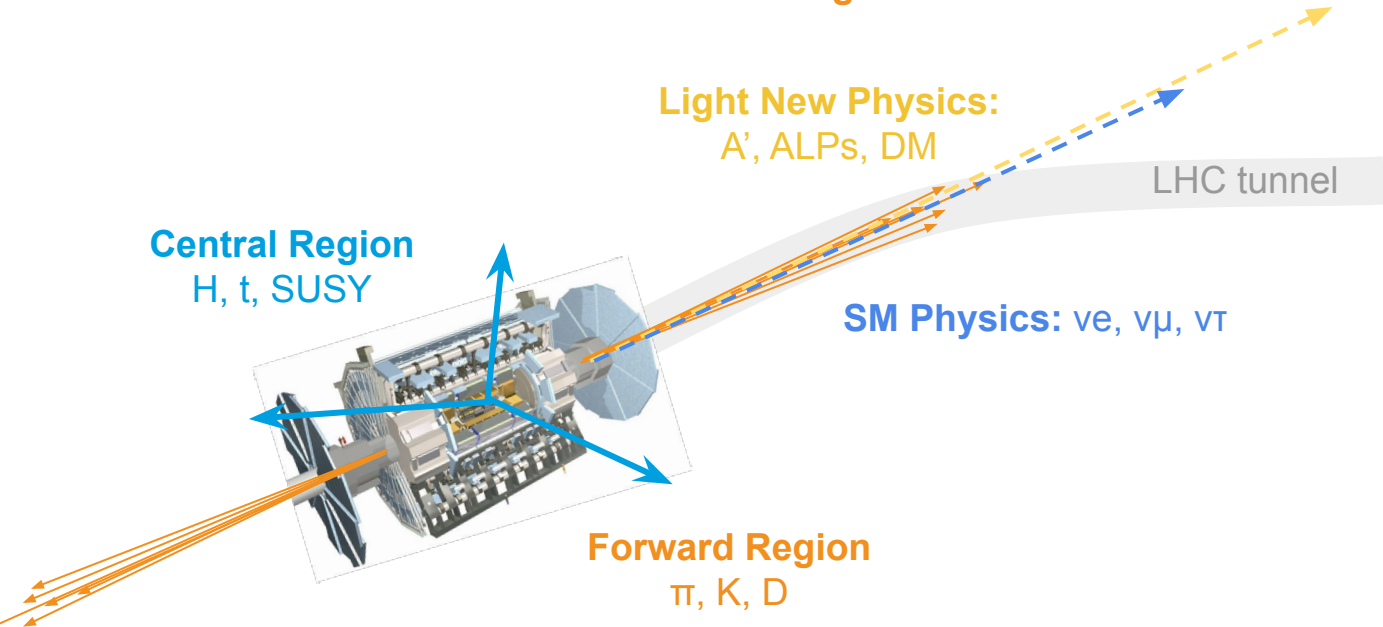


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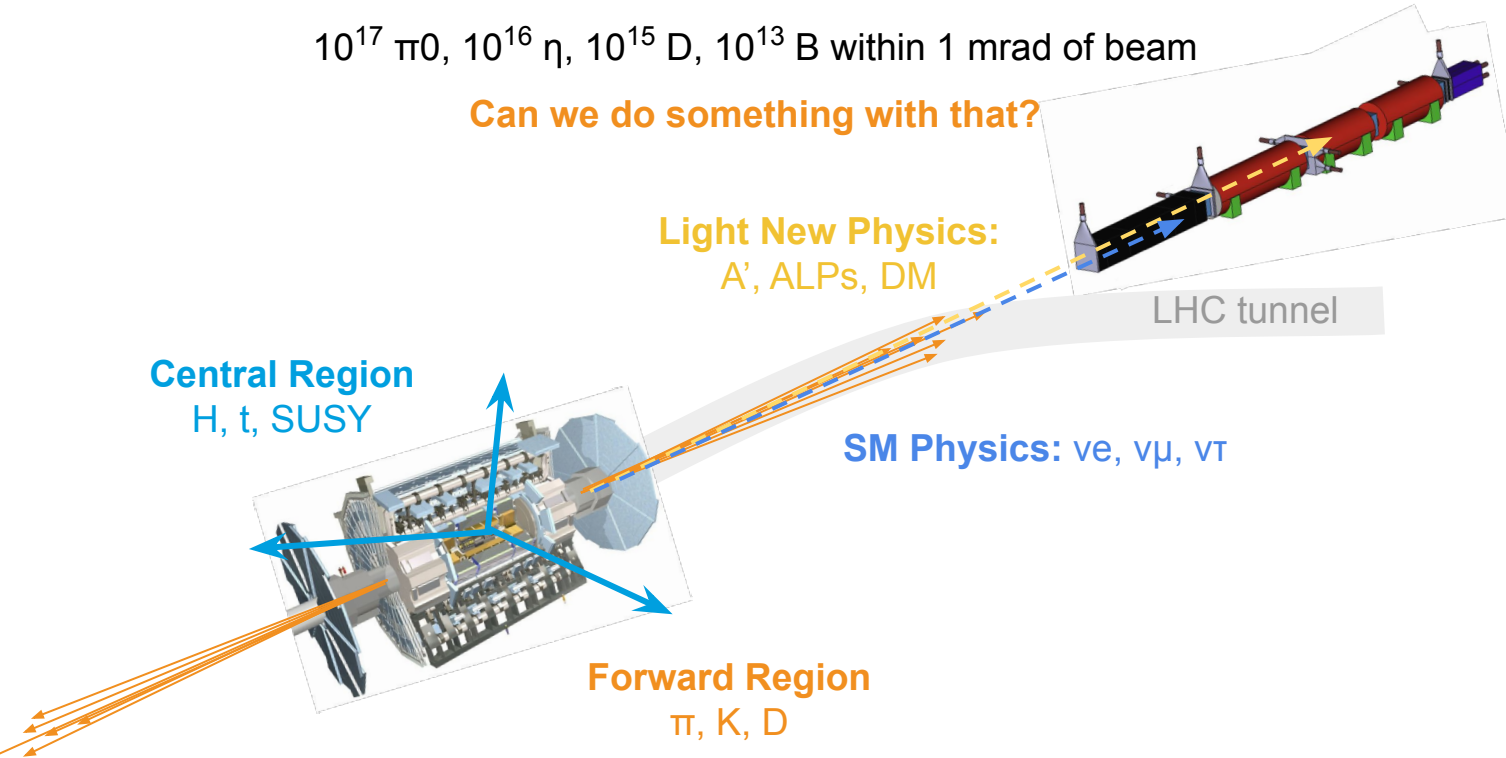
Light New Physics:  
 $A'$ , ALPs, DM

LHC tunnel

Central Region  
 $H$ ,  $t$ , SUSY

SM Physics:  $\nu_e$ ,  $\nu_\mu$ ,  $\nu_\tau$

Forward Region  
 $\pi$ ,  $K$ ,  $D$

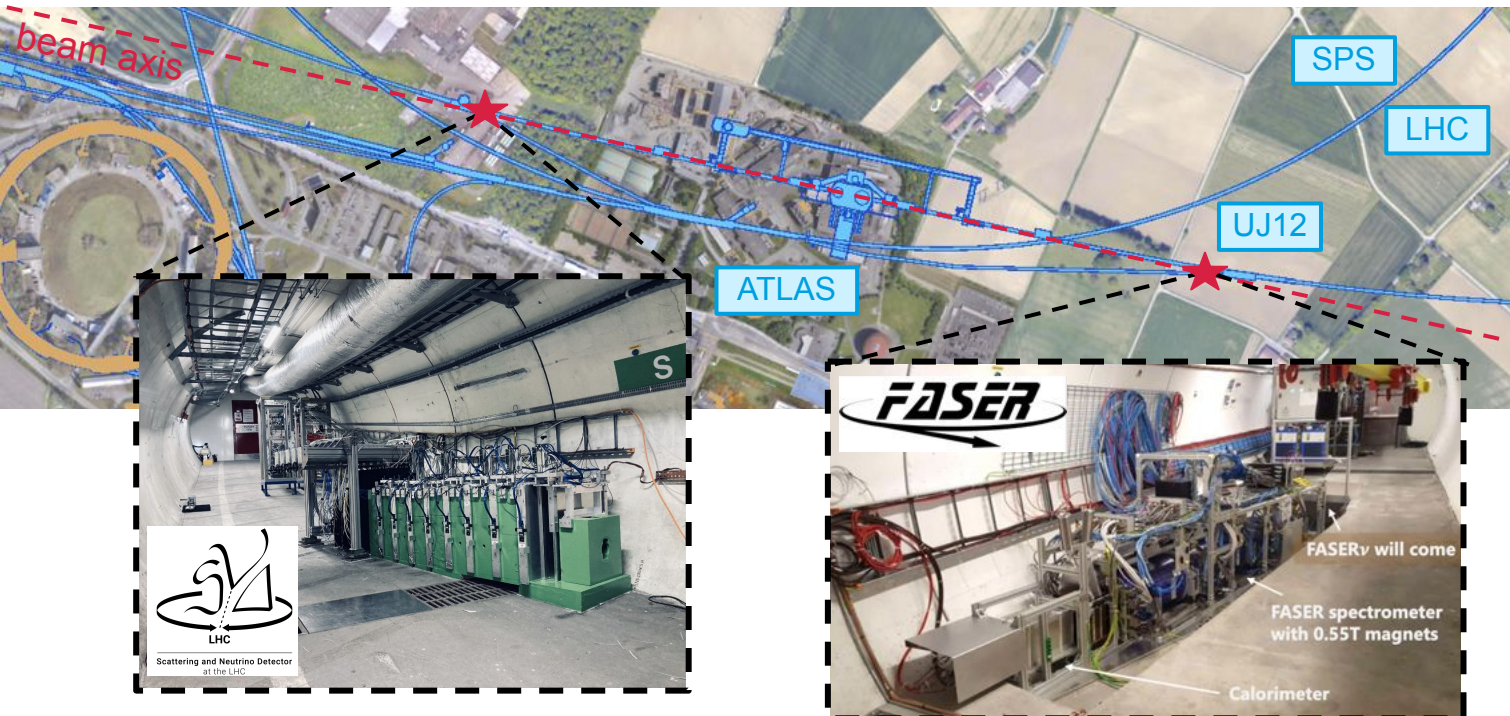


# Experimental Program



# Now: FASER and SND@LHC.

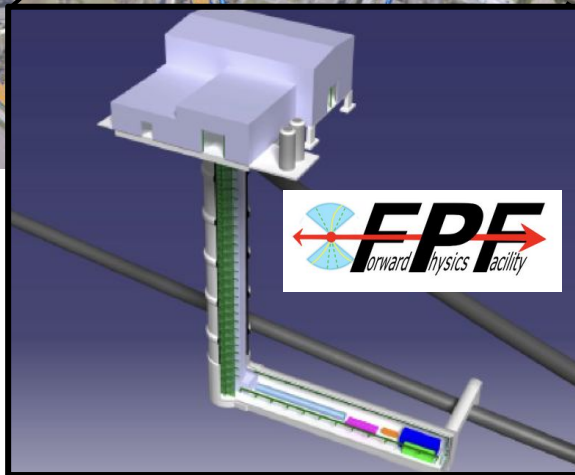
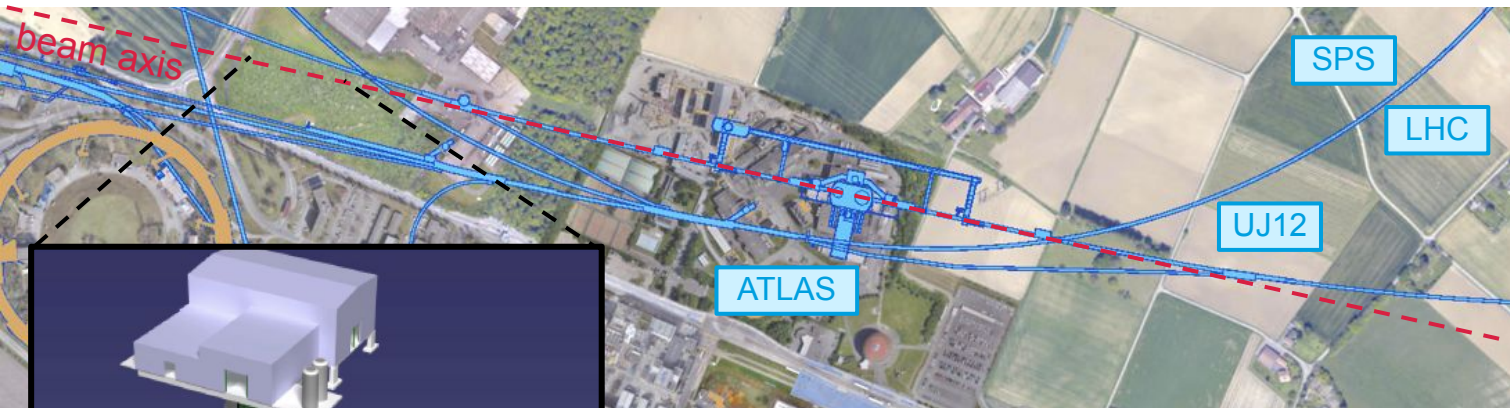
Two new experiments just started their operation in Run 3 of the LHC:  
**SND@LHC** and **FASER**.





# Near Future: FPF.

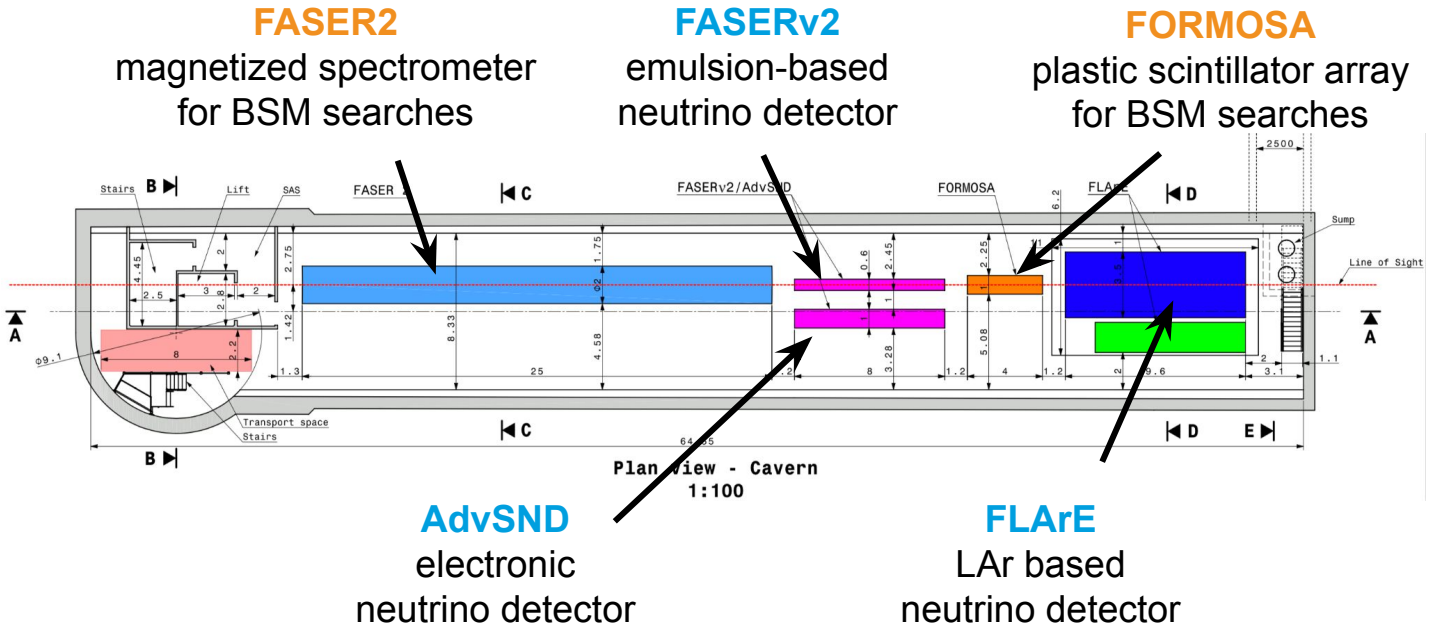
FASER and SND@LHC are highly constrained by 1980's infrastructure that was never intended to support experiments



The proposal: create a dedicated **Forward Physics Facility (FPF)** for the HL-LHC.

# Forward Physics Facility.

The FPF would house a suite of experiments that will greatly enhance the LHC's physics potential for **BSM physics searches**, **neutrino physics** and **QCD**.



# Forward Physics Facility.

**FPF workshop series:**  
[FPF1](#), [FPF2](#), [FPF3](#), [FPF4](#)

**FPF Paper:**  
[2109.10905](#)

~75 pages, ~80 authors

**Snowmass Whitepaper:**  
[2203.05090](#)

~450 pages, ~250 authors

4th Forward Physics Facility Meeting

31 January 2022 to 1 February 2022  
Europe/Zurich timezone

Enter your search term

Overview

- Call for Abstracts
- Timetable
- Contribution List
- My Conference
  - My Contributions
  - Book of Abstracts
- Registration
- Participant List

Starts 31 Jan 2022, 16:00  
Ends 1 Feb 2022, 21:00  
Europe/Zurich

There are no materials yet.

The Forward Physics Facility (FPF) project is moving forward!

At the 4th Forward Physics Facility Meeting we will discuss the facility, experiments, and physics goals of the proposed FPF at the HL-LHC. The meeting takes place just before the completion of the FPF Snowmass White Paper and will provide an opportunity to summarize the current status of the White Paper and the final steps in its preparation. The whole event will be held online.

The Zoom links are:  
Please see sessions (both Monday and Tuesday):  
<https://ucf.zoom.us/j/9159102157>  
[live zoom us](https://ucf.zoom.us/j/9159102157)  
<https://ucf.zoom.us/j/9159102157>  
<https://ucf.zoom.us/j/9159102157>  
<https://ucf.zoom.us/j/9159102157>

**The Forward Physics Facility: Sites, Experiments, and Physics Potential**

Luis A. Anchordoqui,<sup>1,\*</sup> Akitaka Ariga,<sup>2,3</sup> Tomoko Ariga,<sup>4</sup> Weidong Bai,<sup>5</sup> Kinoshita Balazs,<sup>6</sup> Brian Batell,<sup>7</sup> Jamie Boyd,<sup>8</sup> Joseph Bramante,<sup>9</sup> Adrian Carmona, Francesco C. Collor,<sup>10,13</sup> Csilla Csorosi,<sup>14</sup> Matthew Covic, Albert de Roeck,<sup>6</sup> Hans Dembinski,<sup>15</sup> Peter B. Denton,<sup>16</sup> Anton Milani, V. Divan,<sup>17</sup> Liam Dougherty,<sup>18</sup> Herbi K. Dreiner,<sup>19</sup> Yong Yessman Farzan,<sup>20</sup> Jonathan L. Feng,<sup>20,1</sup> Max Fieg,<sup>26</sup> Patrick Fonghith-Ahnt,<sup>28</sup> Alexander Friedland,<sup>29,1</sup> Michael Fusella,<sup>30</sup> Maria Vittoria Garzelli,<sup>30,1</sup> Francesco Giuli,<sup>31</sup> Victor P. Gonzales Francis Halzen,<sup>32</sup> Juan Carlos Hebo,<sup>38,39</sup> Christopher S. Hill, Ameen Ismail,<sup>40</sup> Sulpit Jana,<sup>41</sup> Yu Seon Jeong,<sup>42</sup> Krzysztof Jo Koma,<sup>43</sup> Kevin J. Kelly,<sup>44</sup> Felix Kling,<sup>28,45,1</sup> Rafael Maciula, Abraham,<sup>46</sup> Julien Marchand,<sup>47</sup> Josh McFayden,<sup>48</sup> Mohammed Pavel M. Nadolsky,<sup>50,\*</sup> Nobuchika Okada,<sup>51</sup> John Osborne,<sup>6</sup> Ilia Pandoz,<sup>52,46,\*</sup> Alessandro Papa,<sup>53</sup> Digshi Ran,<sup>54</sup> May Hall R. Adam Ritz,<sup>55</sup> Juan Rojo,<sup>56</sup> Iva Starevic,<sup>56,\*</sup> Christiane Schab, Holger Schulz,<sup>59</sup> Dipan Sengupta,<sup>60</sup> Terhijana Sijstani,<sup>61,\*</sup> Tyler B. Anna Staato,<sup>62</sup> Antoni Szczurek,<sup>63</sup> Zahra Tabrizi,<sup>63</sup> Sebastia Yu-Dai Tsai,<sup>26,46</sup> Douglas Tucker,<sup>46</sup> Martin W. Winkler,<sup>67</sup> Kevin

Submitted to the US Community Study on the Future of Particle Physics (Snowmass 2021)



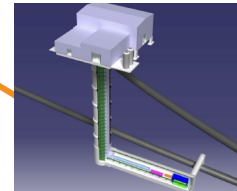
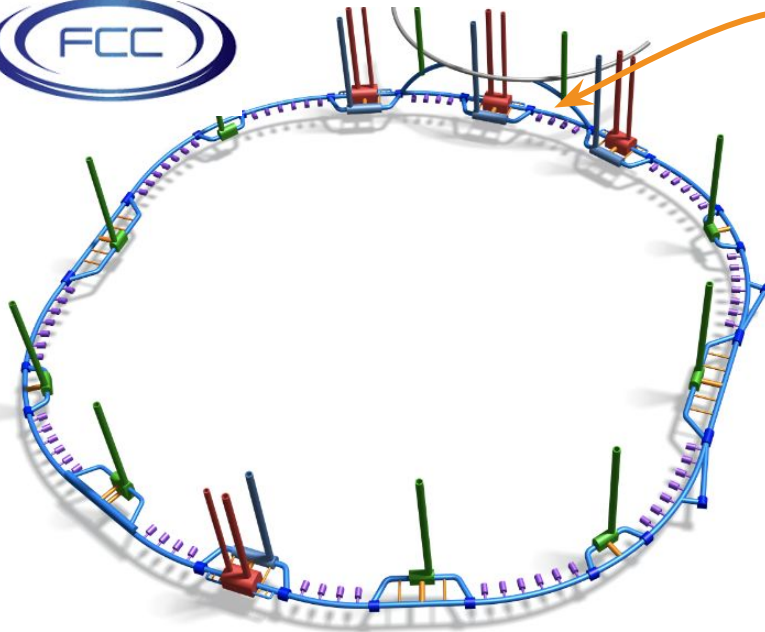
**The Forward Physics Facility at the High-Luminosity LHC**

High energy collisions at the High-Luminosity Large Hadron Collider (LHC) produce a large number of particles along the beam collision axis, outside of the acceptance of existing LHC experiments. The proposed Forward Physics Facility (FPF), to be located several hundred meters from an LHC interaction point and shielded by concrete and rock, will host a suite of experiments to probe standard model processes and search for physics beyond the standard model (BSM). In this report, we review the status of the civil engineering plans and the experiments to explore the diverse physics signals that can be uniquely probed in the forward region. FPF experiments will be sensitive to a broad range of BSM physics through searches for new particle scattering or decay signatures and deviations from standard model expectations in high statistics analyses with TeV neutrinos in this low-background environment. High statistics neutrino detection will trace back to fundamental topics in perturbative and non-perturbative QCD and in weak interactions. Experiments at the FPF will enable synergies between forward particle production at the LHC and astroparticle physics to be exploited. We report here on these physics topics, on infrastructure, detector and simulation studies, and on future directions to realize the FPF's physics potential.

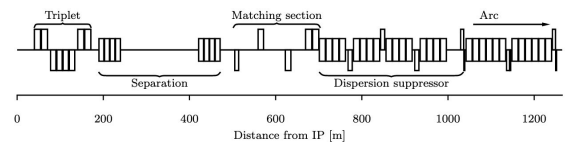
# Far Future: FPF@FCC.

Similar experiments should also be considered for future colliders such the FCC-hh.

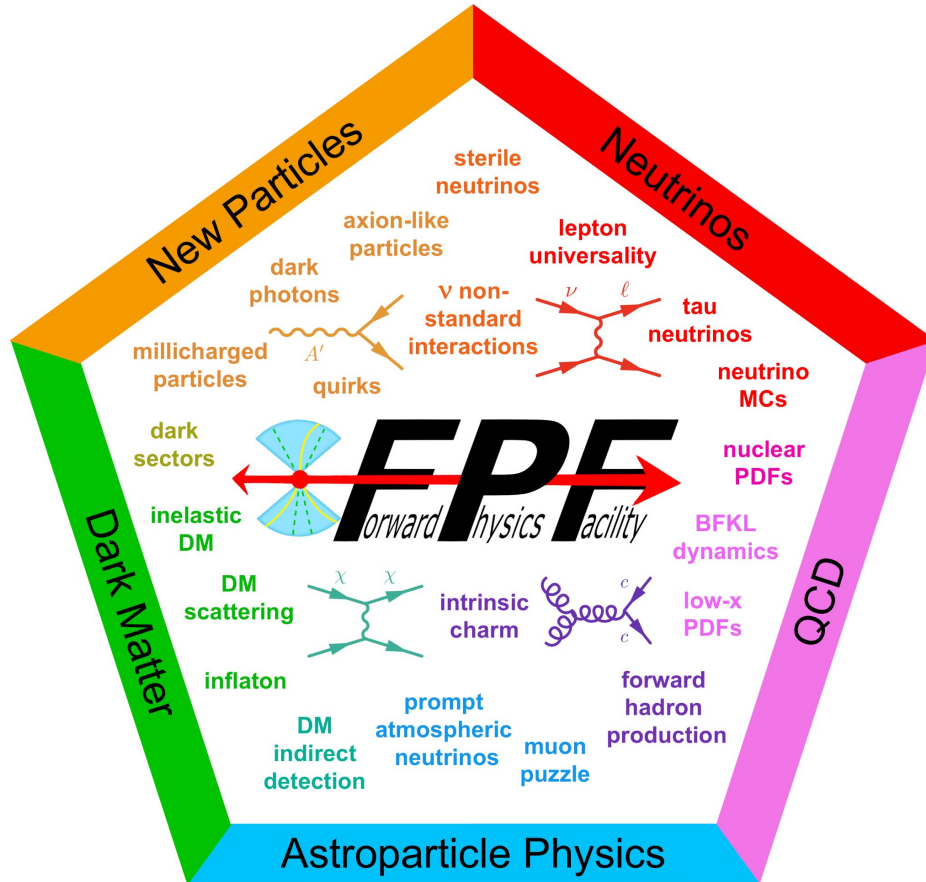
Dedicated facility can be included from the beginning.



location ~1.5km downstream  
from IP possible [2007.12058](#)



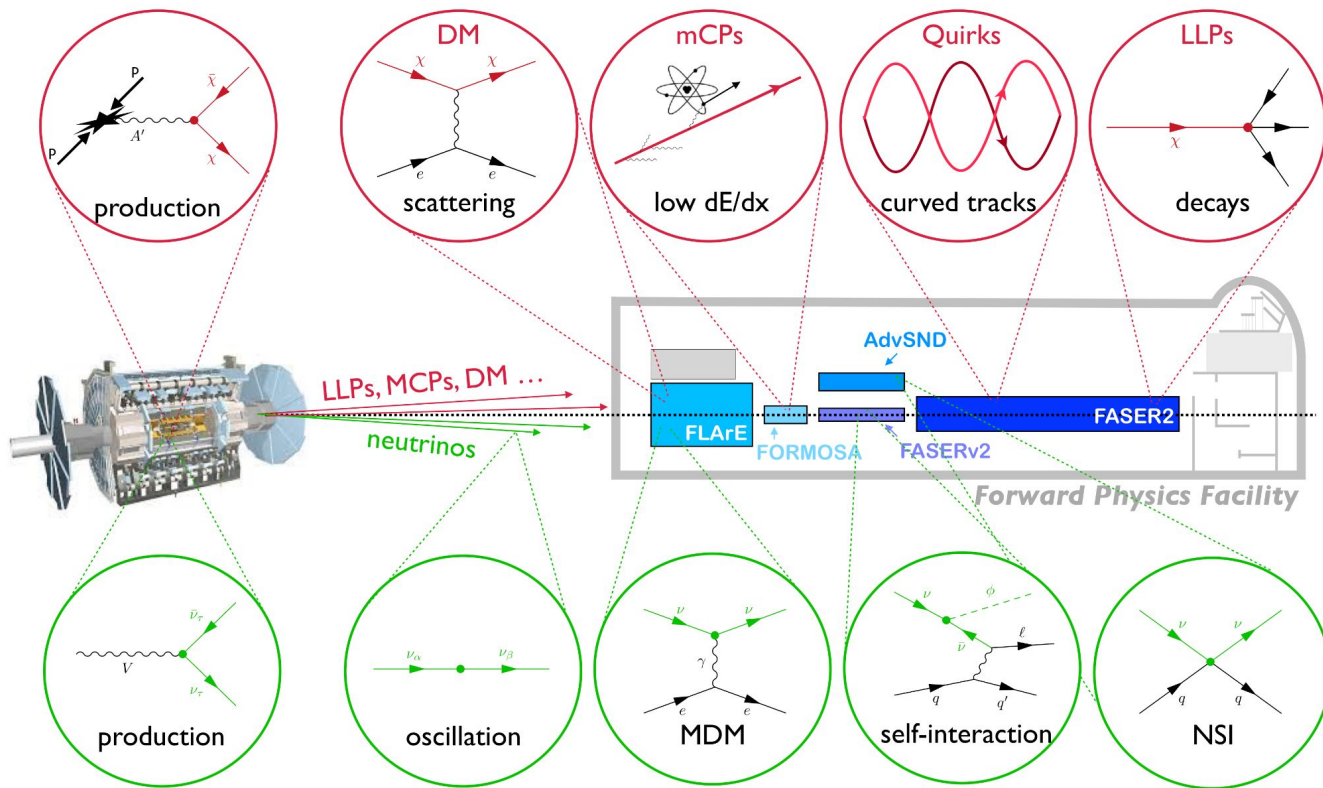
# Physics Potential.



# BSM Physics Searches

# Searches for BSM Physics.

## dark sector searches

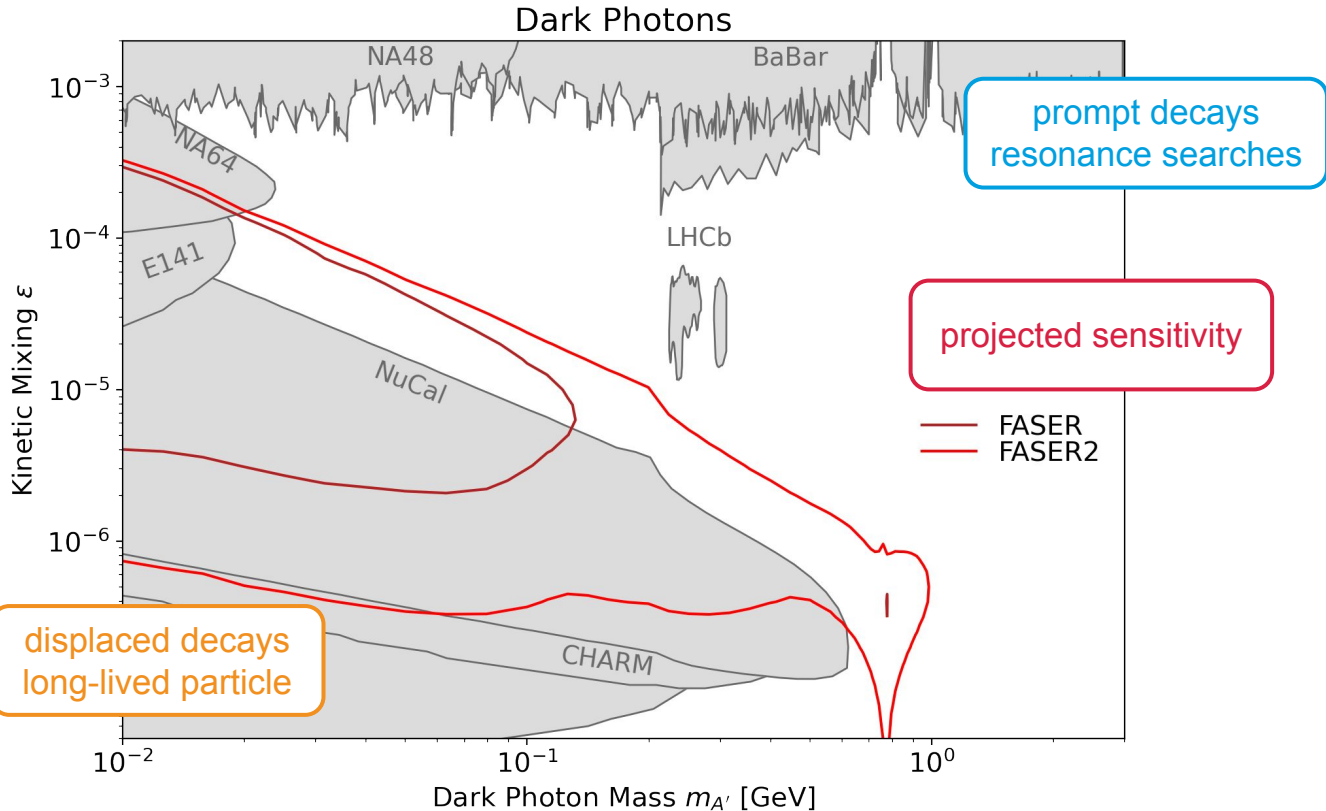


## BSM neutrino physics

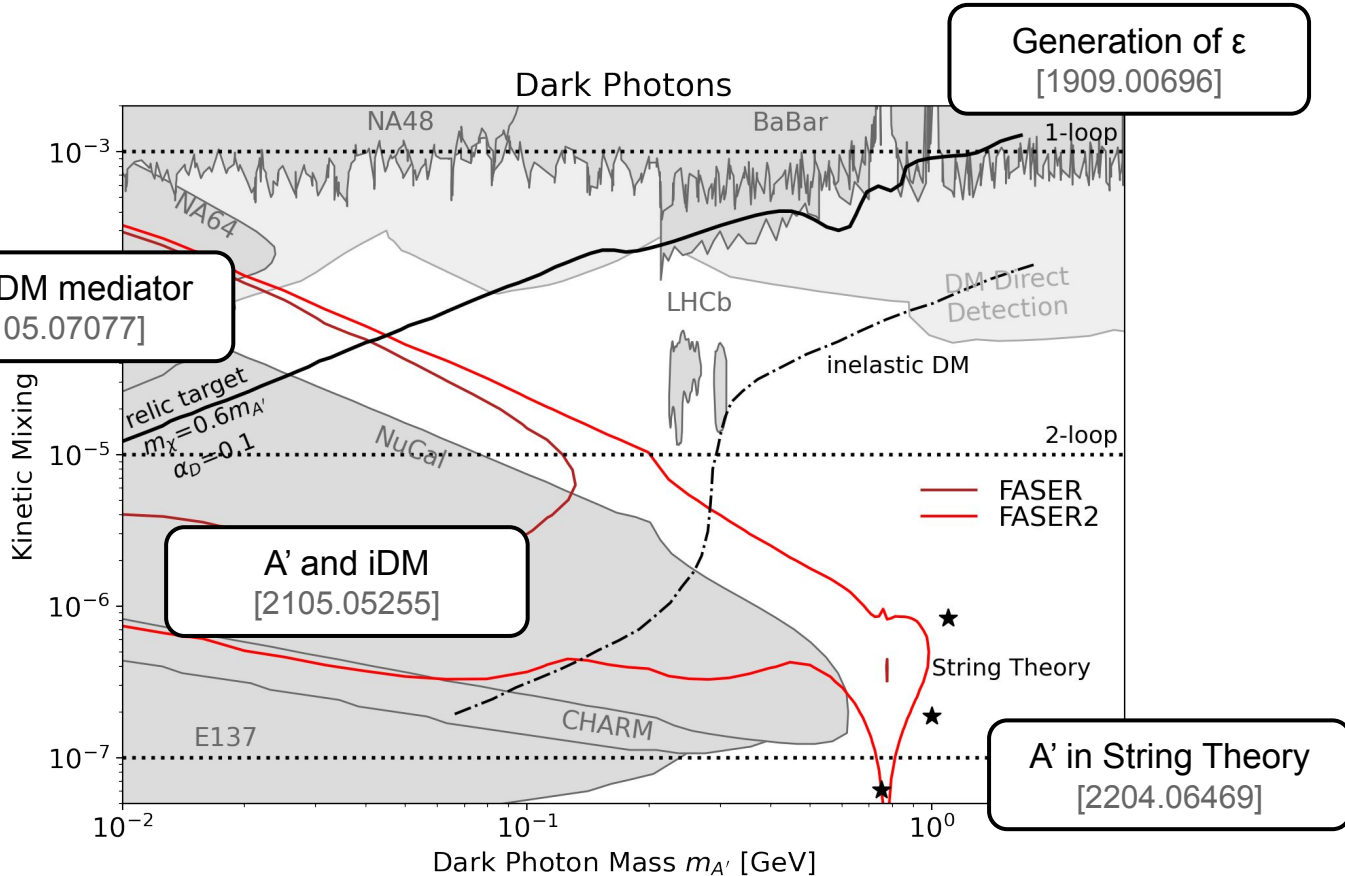


# Long-Lived Particle Searches.

Dark Photon = gauge boson mixing with photon:  $\mathcal{L} \sim -\frac{1}{2}m_{A'}^2 A'^2 - \epsilon e q_f \bar{f} A' f$

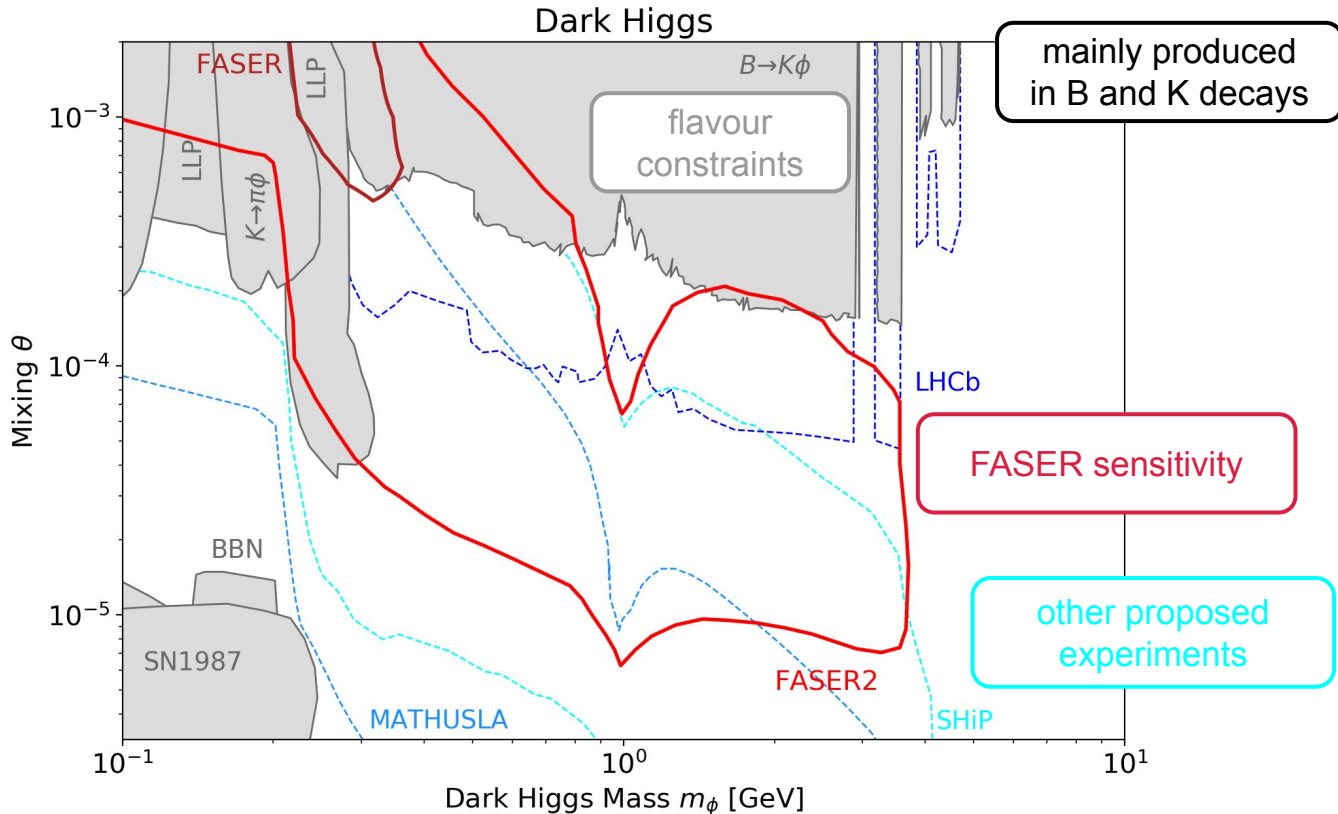


# Long-Lived Particle Searches.

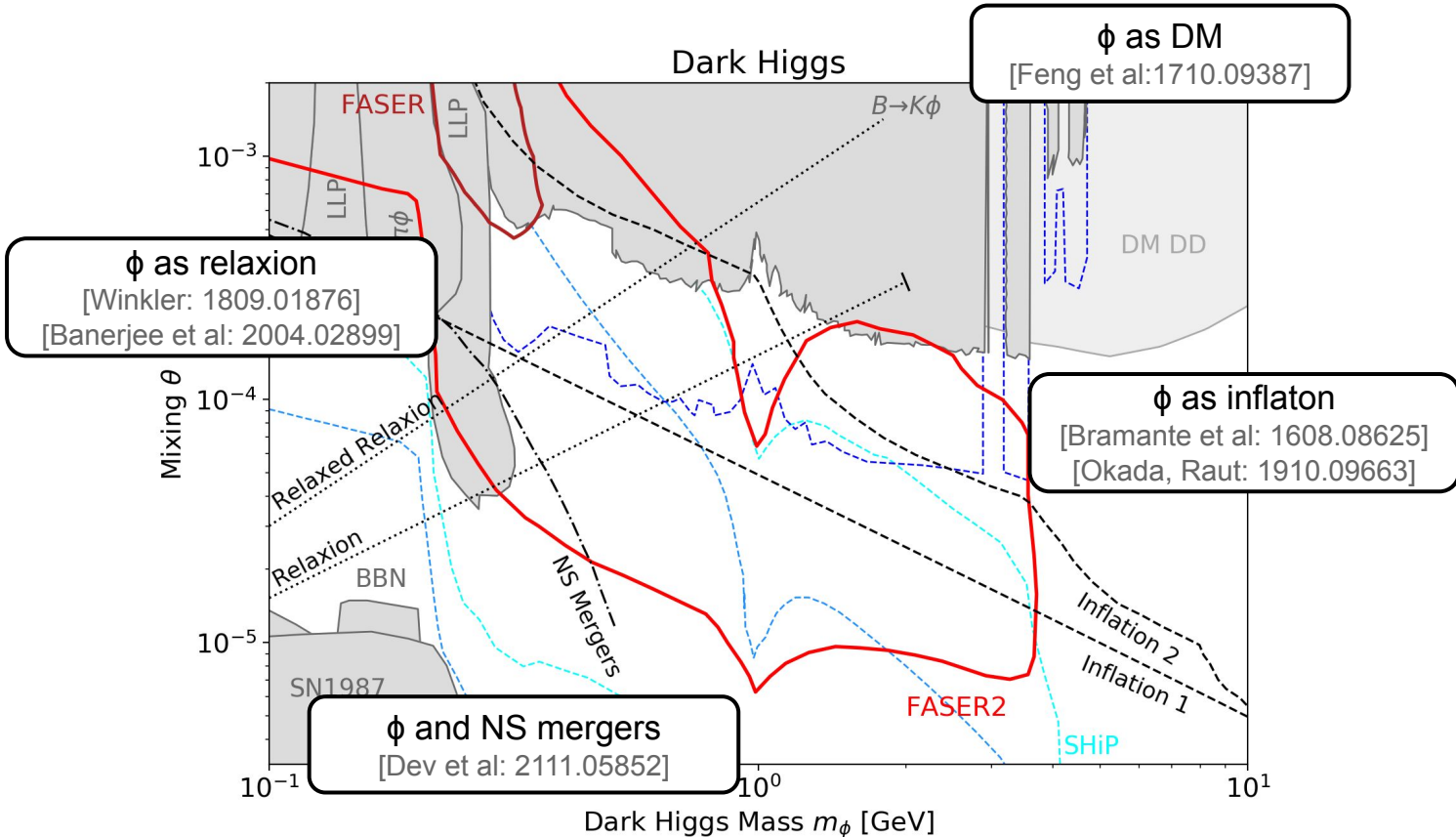


# Long-Lived Particle Searches.

Dark Higgs = light scalar mixing with SM Higgs:  $\mathcal{L} \supset m_\phi^2 \phi^2 + \sin \theta y_f \phi \bar{f} f$



# Long-Lived Particle Searches.



# Long-Lived Particle Searches.

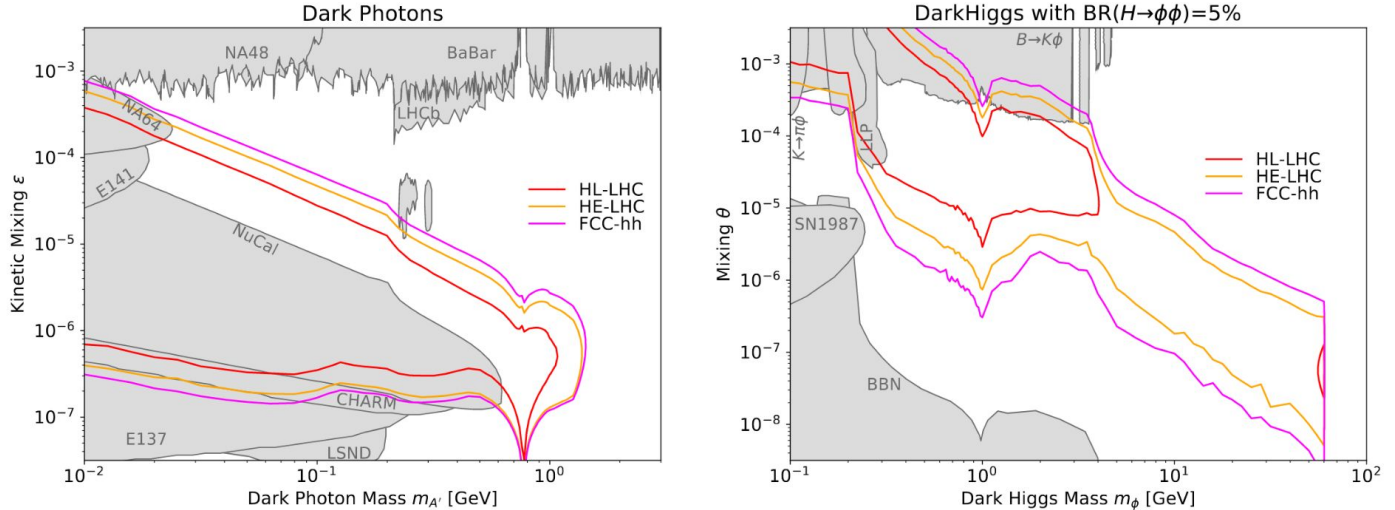
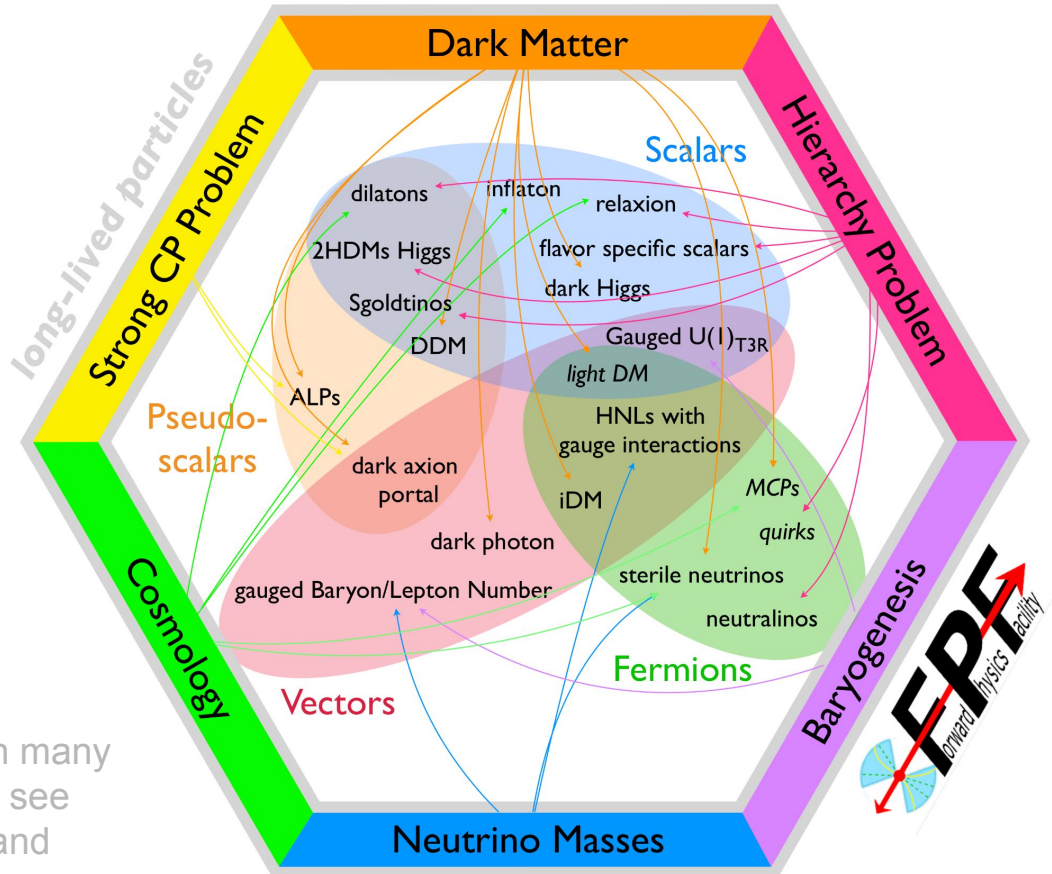


FIG. 3. Sensitivity reach lines obtained for the FASER 2 detector to take data during the HL-LHC era (red solid line) and for similar detectors operating at the future hadron colliders: HE-LHC (orange) and FCC-hh/SppC (purple). The details of the assumed detector design are given in Table II. The reach plots are shown for the dark photon model in a  $(m_{A'}, \epsilon)$  plane (left) and for the dark Higgs boson model in a  $(m_\phi, \theta)$  plane (right). In both cases, current bounds on the model parameter space are shown with gray-shaded regions (see the text for details).

# Long-Lived Particle Searches.



For details on many more models see [1811.12522](https://arxiv.org/abs/1811.12522) and [2203.05090](https://arxiv.org/abs/2203.05090).



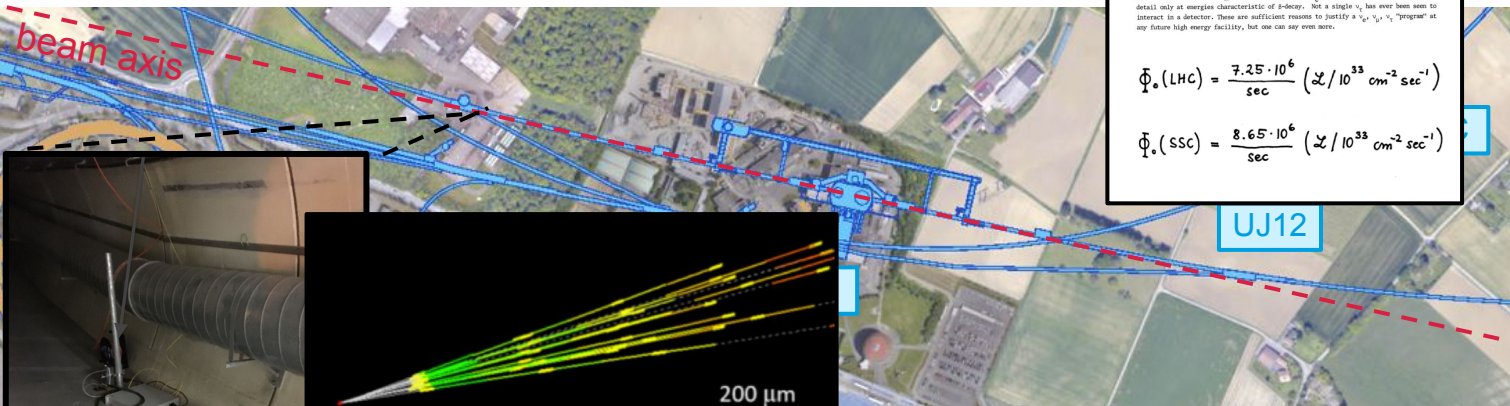
# SM Physics Measurements



# Neutrinos at Colliders.

There is a huge flux of neutrinos in the forward direction, mainly from  $\pi$ , K and D meson decays.

[De Rujula et al. (1984)]



NEUTRINO AND MUON PHYSICS IN THE COLLIDER MODE OF FUTURE ACCELERATORS<sup>1</sup>

A. De Rújula and F. Neri  
CERN, Geneva, Switzerland

**ABSTRACT**  
Extracted beam and fixed target facilities at future colliders (the SSC and the LHC) may be respectively improved by economic and "technological" considerations. Neutrino and muon physics in the multi-TeV range would appear not to be an option for these machines. We partially reverse this conclusion by examining the characteristics of the "proton"  $\nu_\mu$ ,  $\nu_e$ ,  $\nu_\tau$  and  $\bar{\nu}$  beams necessarily produced (for fixed at the pp or pA interactions). The neutrino beams from a high luminosity (pp) collider are not such and not intense like the neutrino beams from the colliders. They require no muon shielding. We show some of the muon interactions are intense and energetic enough to study up to 10<sup>10</sup> interactions with considerable statistics and a  $\sqrt{s}$  coverage well beyond the presently available one. The physics program allowed by these proton beams is a strong advocate of machines with the highest possible luminosity per unit pp colliders.

1. INTRODUCTION

The interactions of muons and muon-neutrinos with nucleons have not been experimentally studied with beams of energy in the TeV range. The  $\nu\mu$  interactions have been analyzed in detail only at energies characteristic of S-decay. Not a single  $\nu_\mu$  has ever been seen to interact in a detector. These are sufficient reasons to justify a  $\nu_\mu$ ,  $\nu_e$ ,  $\nu_\tau$  "program" at any future high energy facility, but one can say even more.

$$\Phi_{\nu}^{\mu}(\text{LHC}) = \frac{7.25 \cdot 10^6}{\text{sec}} \left( \mathcal{L} / 10^{33} \text{ cm}^{-2} \text{ sec}^{-1} \right)$$

$$\Phi_{\nu}^{\mu}(\text{SSC}) = \frac{8.65 \cdot 10^6}{\text{sec}} \left( \mathcal{L} / 10^{33} \text{ cm}^{-2} \text{ sec}^{-1} \right)$$

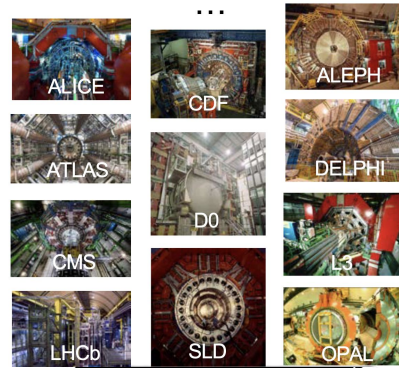
In 2018, the **FASER** collaboration placed  $\sim 30$  kg **pilot emulsion detectors** in T118 for a few weeks.

First neutrino interaction candidates were **reported**.

[FASER, 2105.06197]

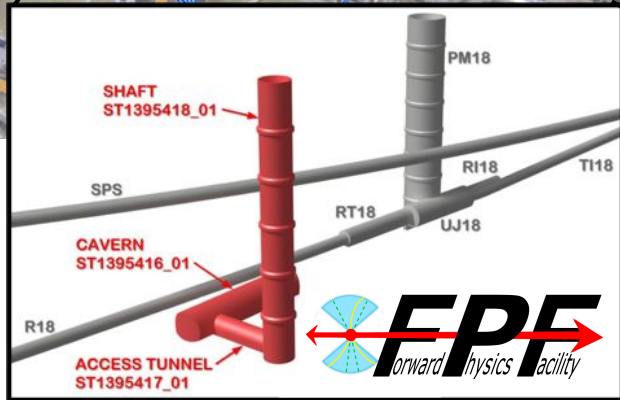
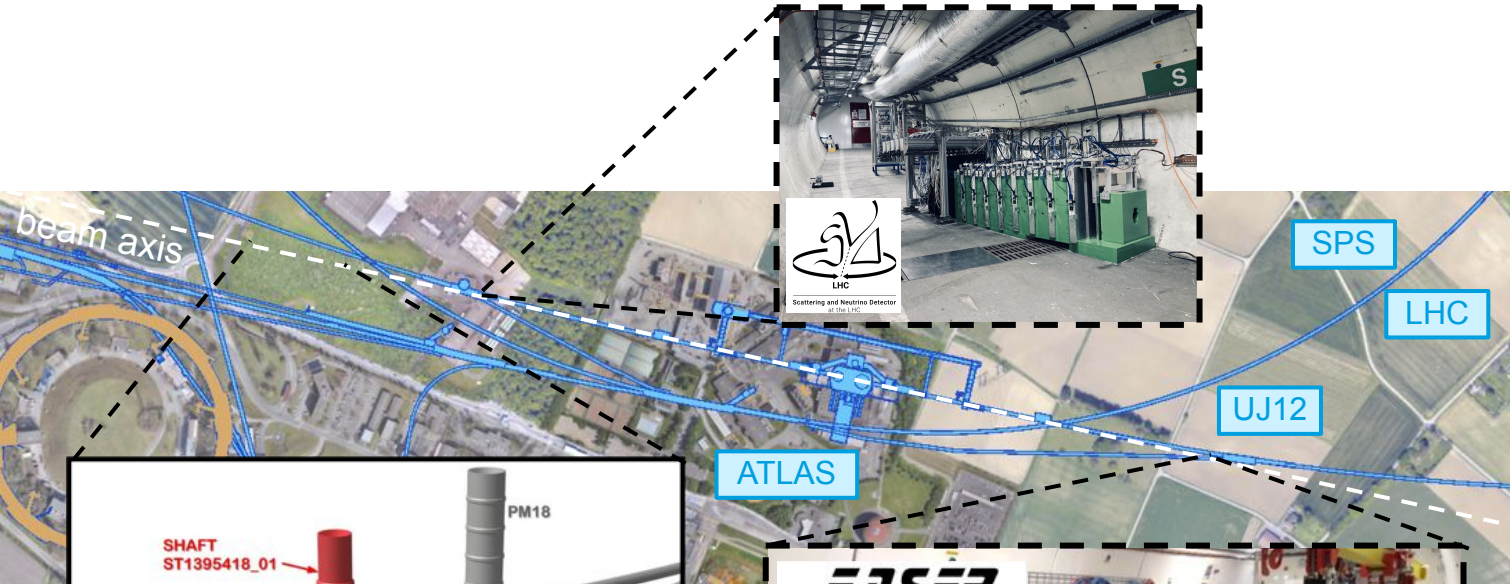
# Neutrinos at Colliders.

FASER Pilot Detector  
suitcase-size, 4 weeks  
\$0 (recycled parts)  
6 neutrino candidates



all previous collider detectors  
building-size, decades ~\$1B  
0 neutrino candidates

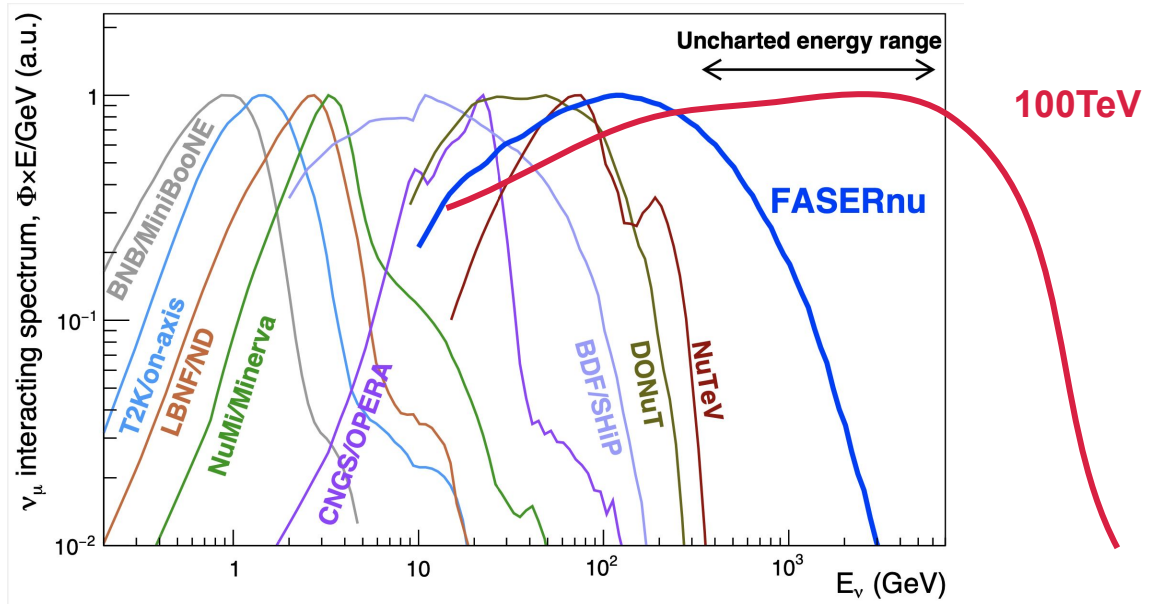
# Neutrinos at Colliders.



new LHC experiment

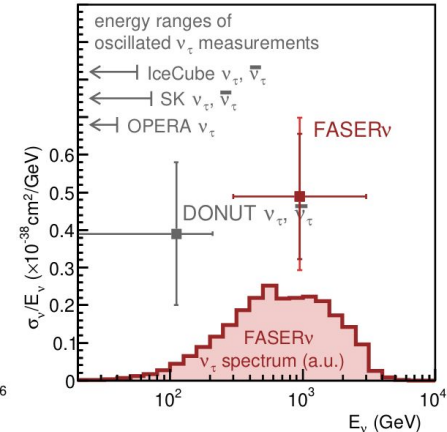
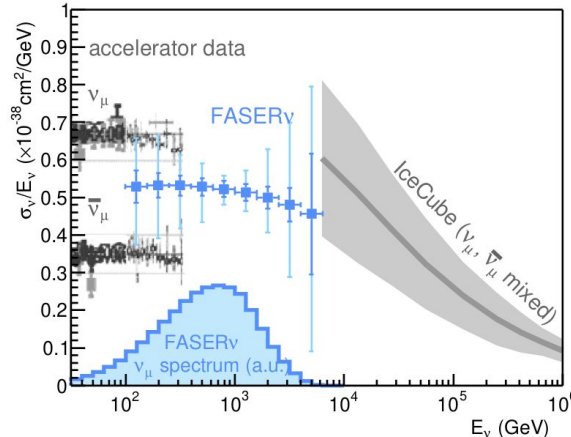
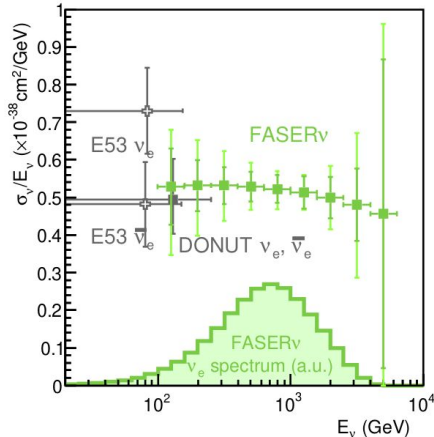
# Neutrinos at Colliders.

Colliders provides a **strongly collimated** beam of **TeV energy** neutrinos of **all three flavours** in the far forward direction.



# Neutrinos Physics

LHC provides a **strongly collimated** beam of **TeV energy** neutrinos of **all three flavours** in the far forward direction.



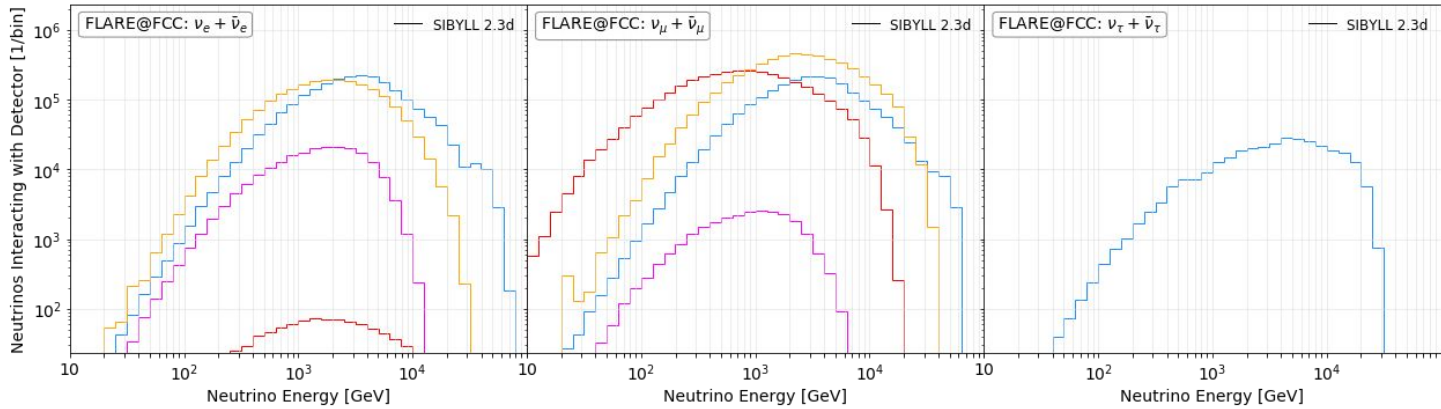
FASER $\nu$  and SND@LHC will detect  $O(10k)$  neutrinos.  
(including 10s of tau neutrinos)

Proposed FPF experiment have potential to detect  $O(1M)$  neutrinos.  
(including thousands of tau neutrinos)



# Neutrinos Physics

neutrino flux estimating using fast simulation and geometry from [2007.12058](#)



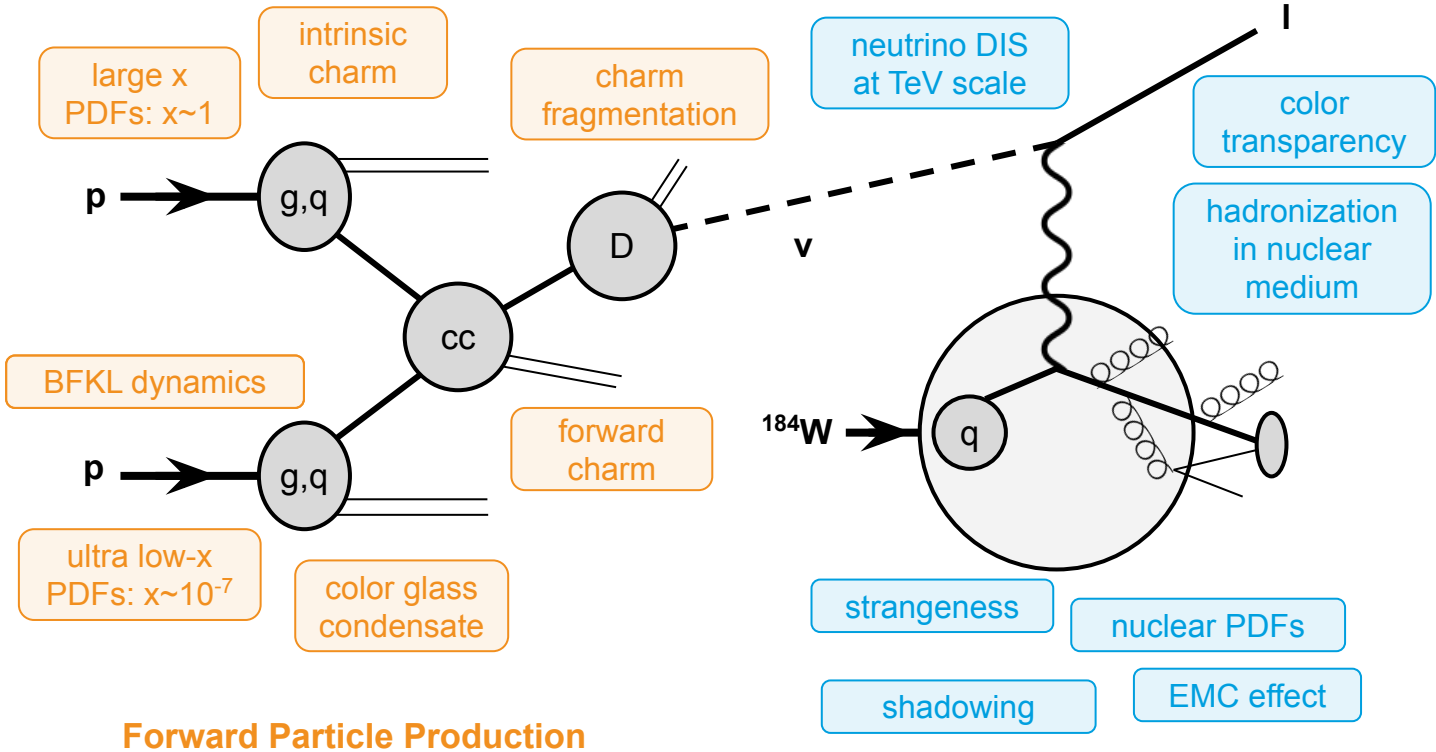
15M/10ton

9M/10ton

300k/10ton

bigger target masses of up to kton could be possible (NuTeV was 0.7kton)  
→ 30M tau neutrinos

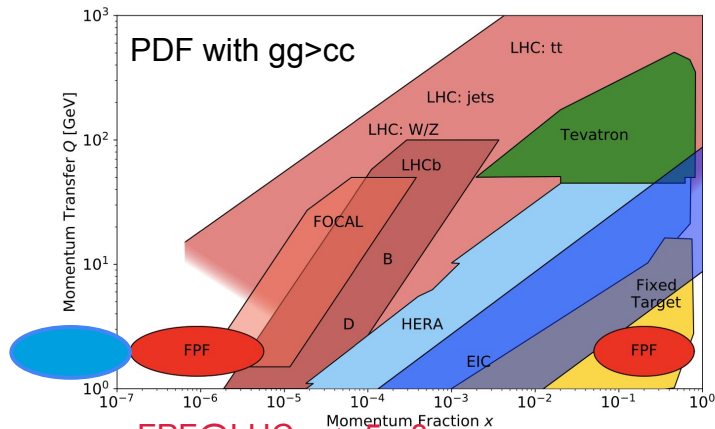
## TeV Energy Neutrino Interaction



Forward Particle Production



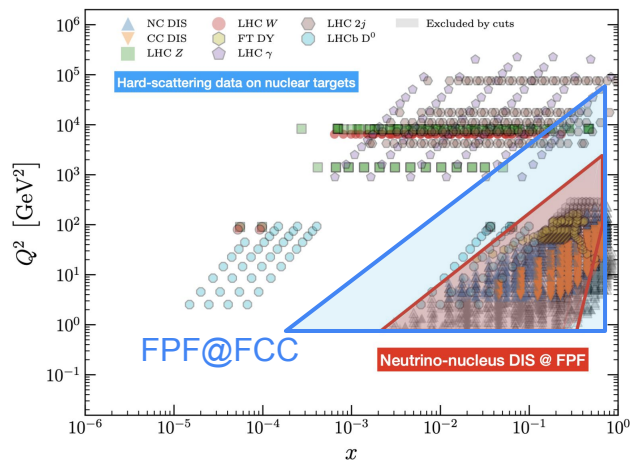
# FPF @ Future Colliders.



FPF@LHC:  $x > 5e-8$

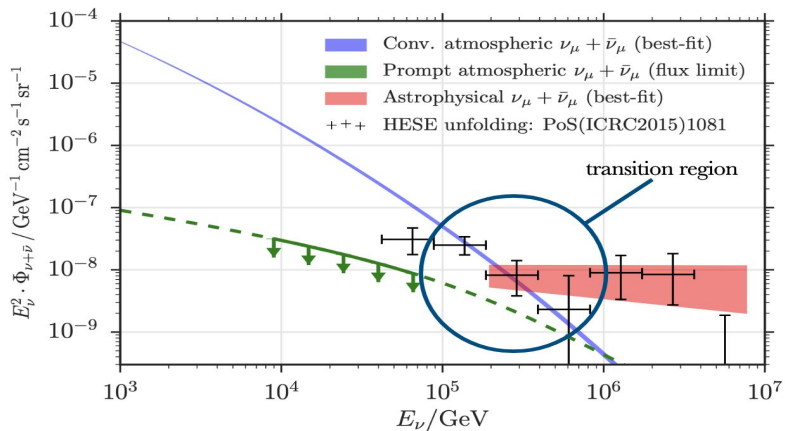
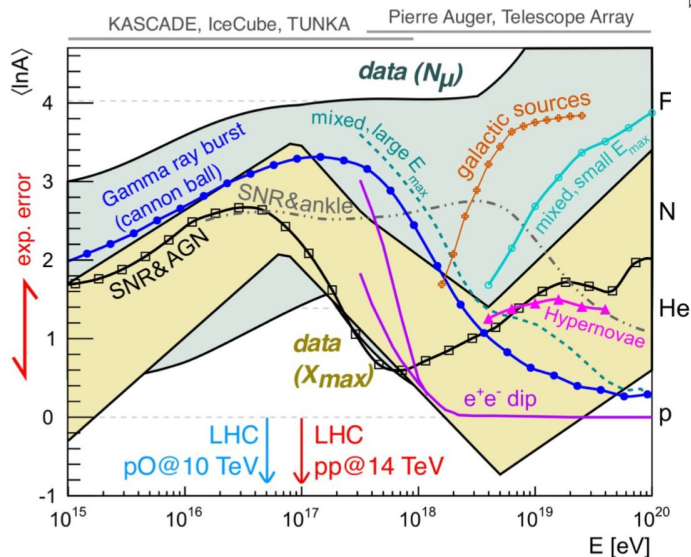
FPF@FCC:  $x > 9e-10$

PDF via  $\nu$ -scattering:  $x \sim 1/E\nu$



# Astroparticle Physics.

forward **charm** production at the LHC  
 ↓  
 constraints on **prompt atmospheric neutrino flux** at IceCube

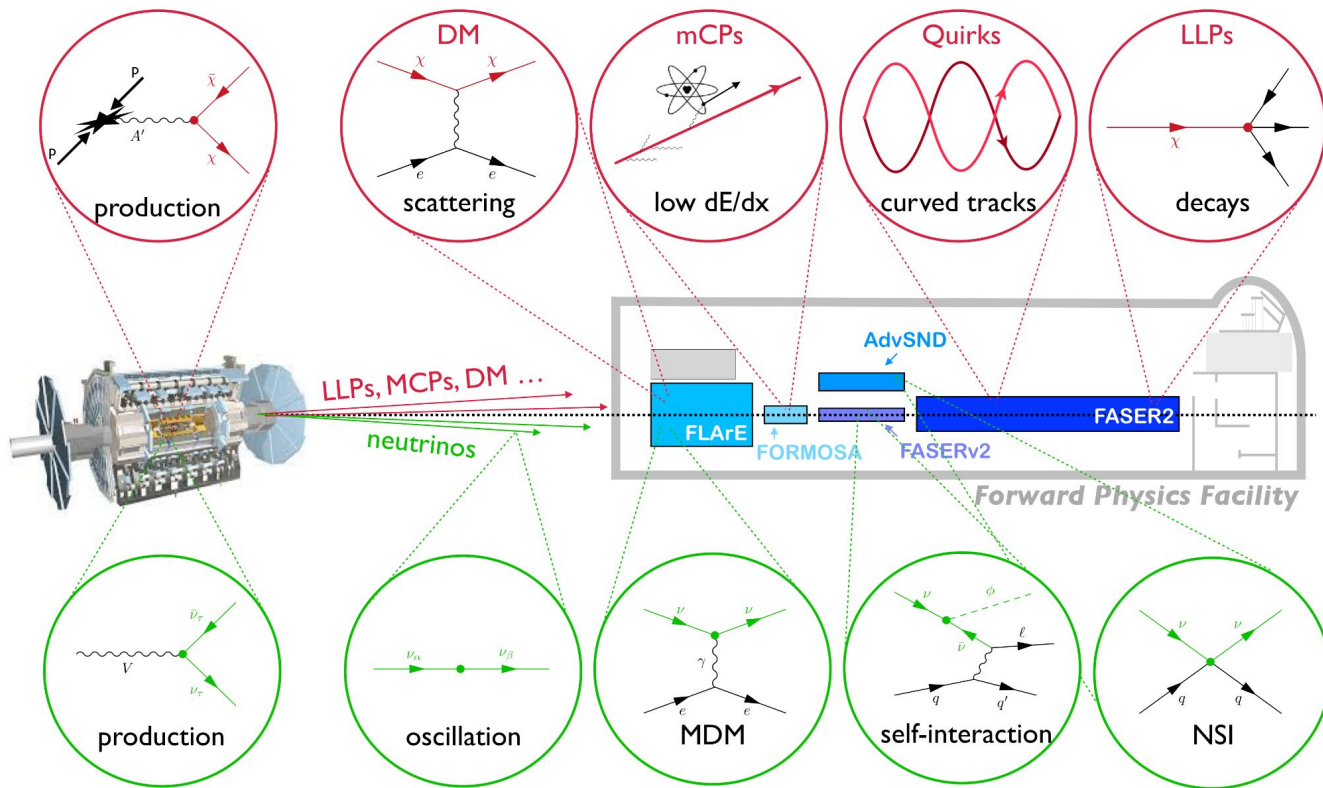


cosmic ray muon puzzle:  
 observed excess of muons compared to hadronic interaction models

forward **pion/kaons** fluxes will provide crucial input

# Searches for BSM Physics.

## dark sector searches



## BSM neutrino physics

# Summary.

FASER and SND@LHC will soon start to take data in LHC's forward direction.

The FPF is proposed to continue this program during the HL LHC era.

Significant extension of the LHC's physics program.

Similar experiments should also be considered when designing future colliders!

