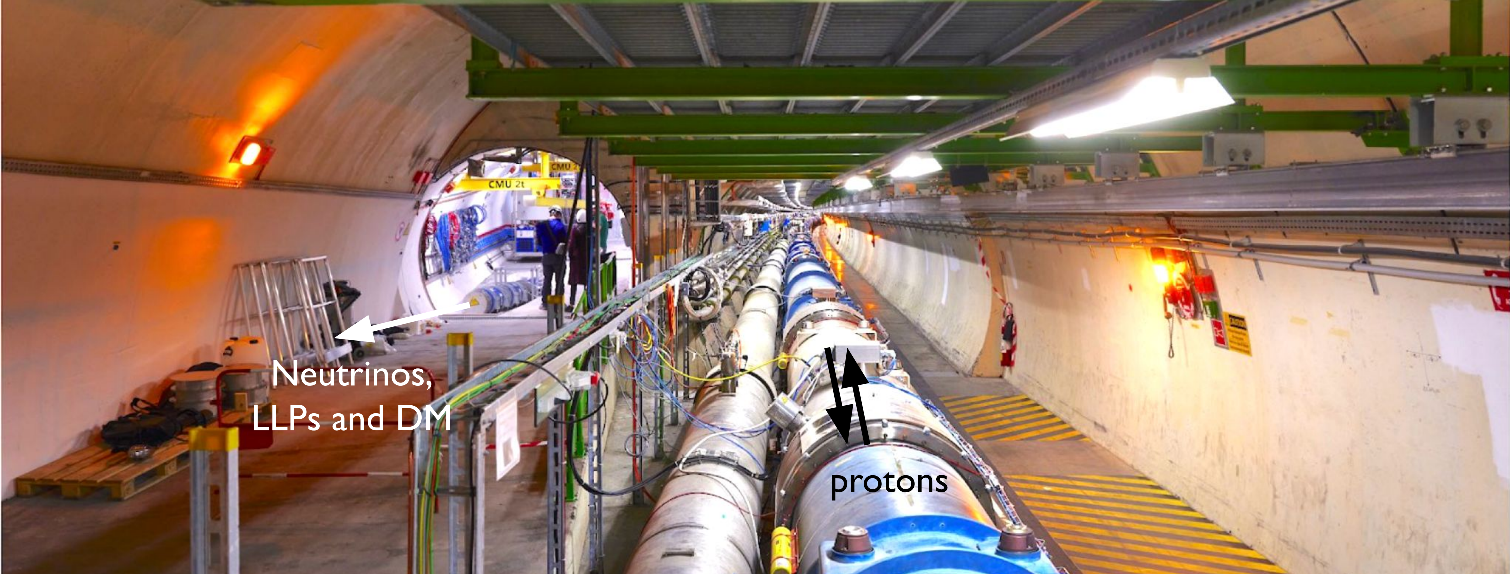
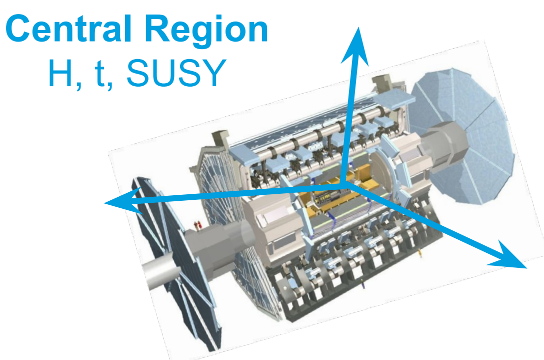


Forward Physics Facility at the FCC.

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

One Slide of Motivation.

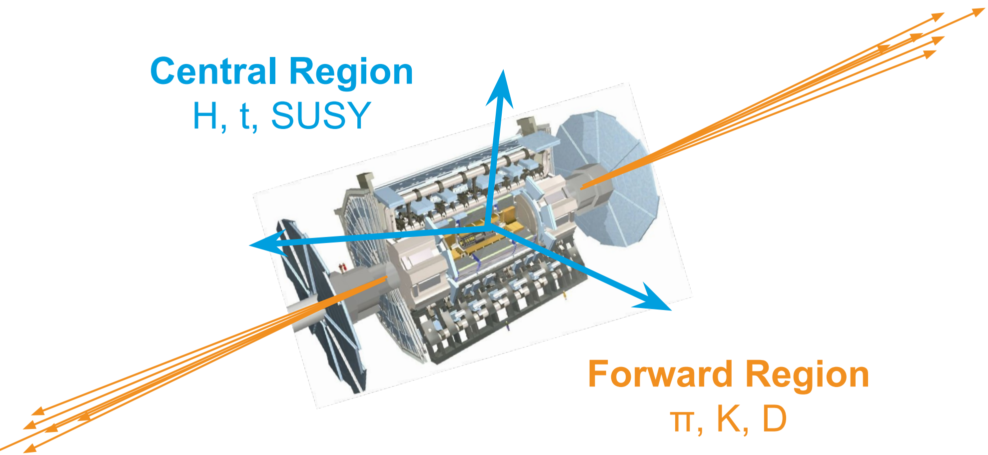


One Slide of Motivation.

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

10^{17} π0, 10^{16} η, 10^{15} D, 10^{13} B within 1 mrad of beam

Can we do something with that?



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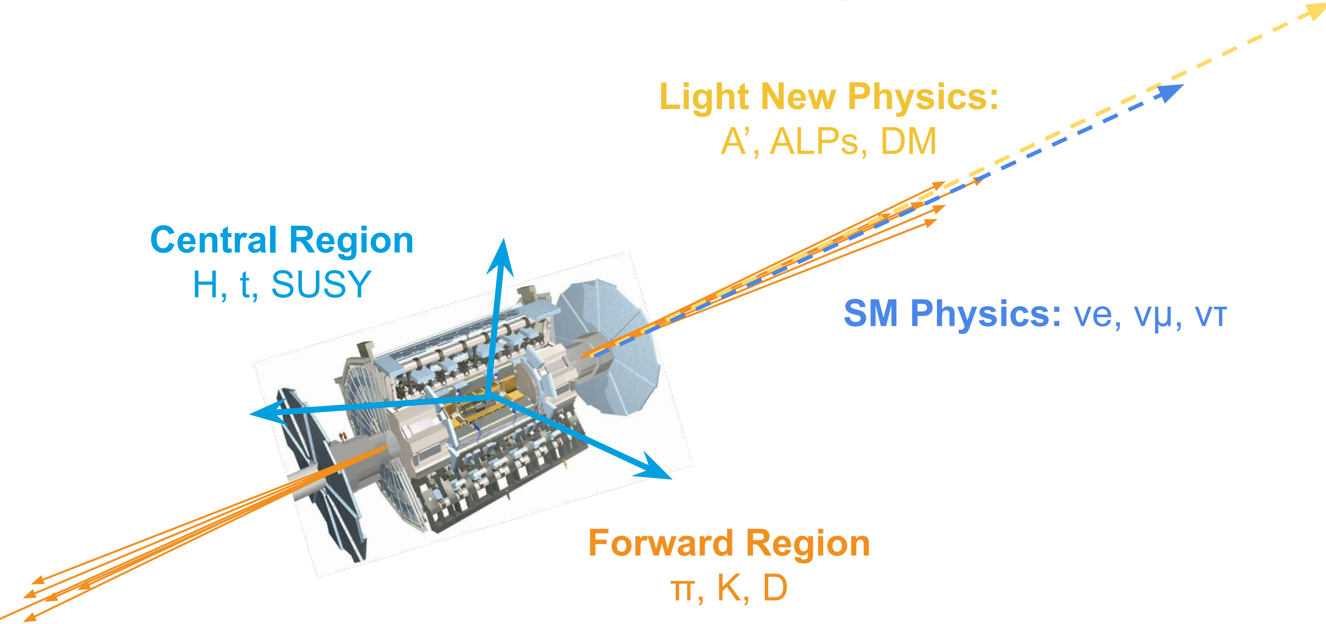

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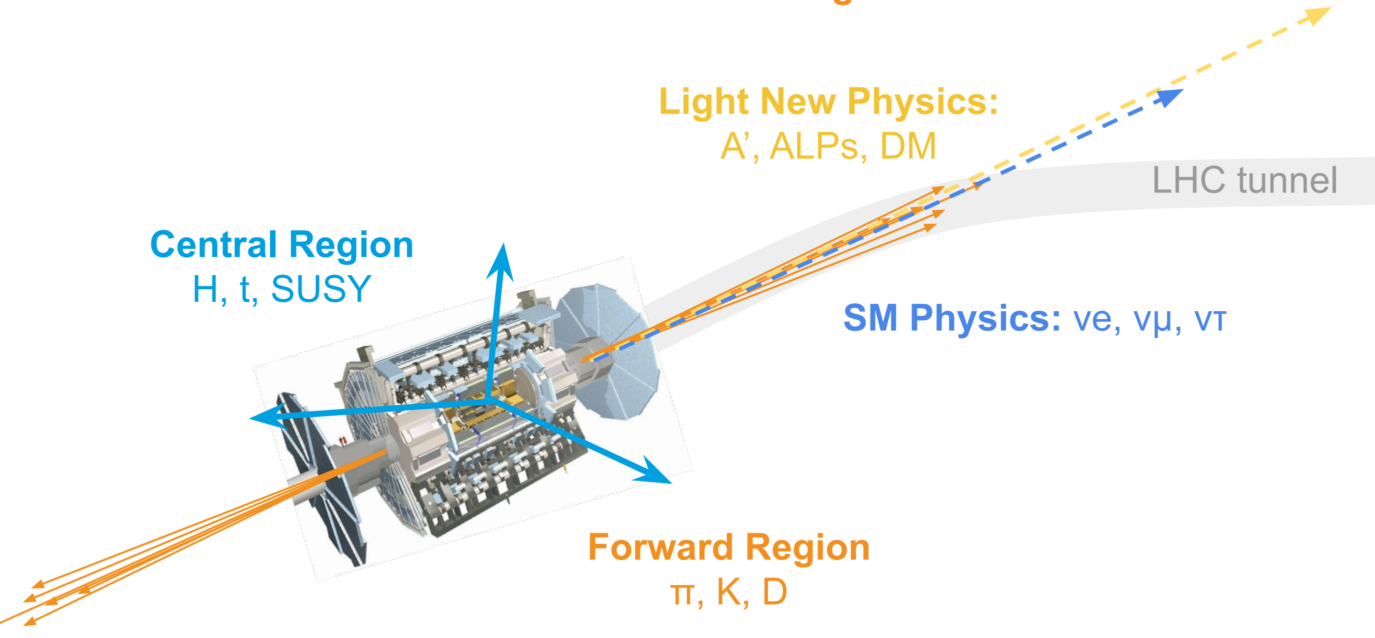

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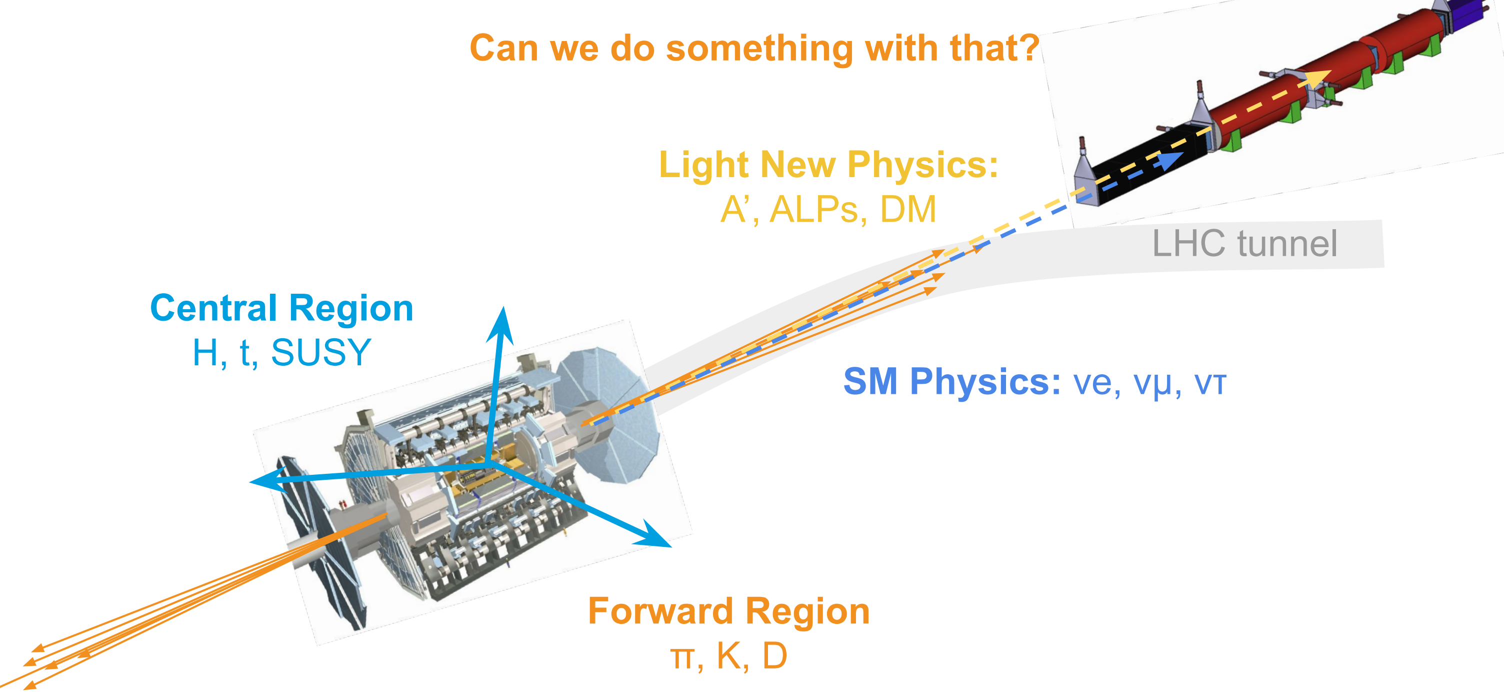
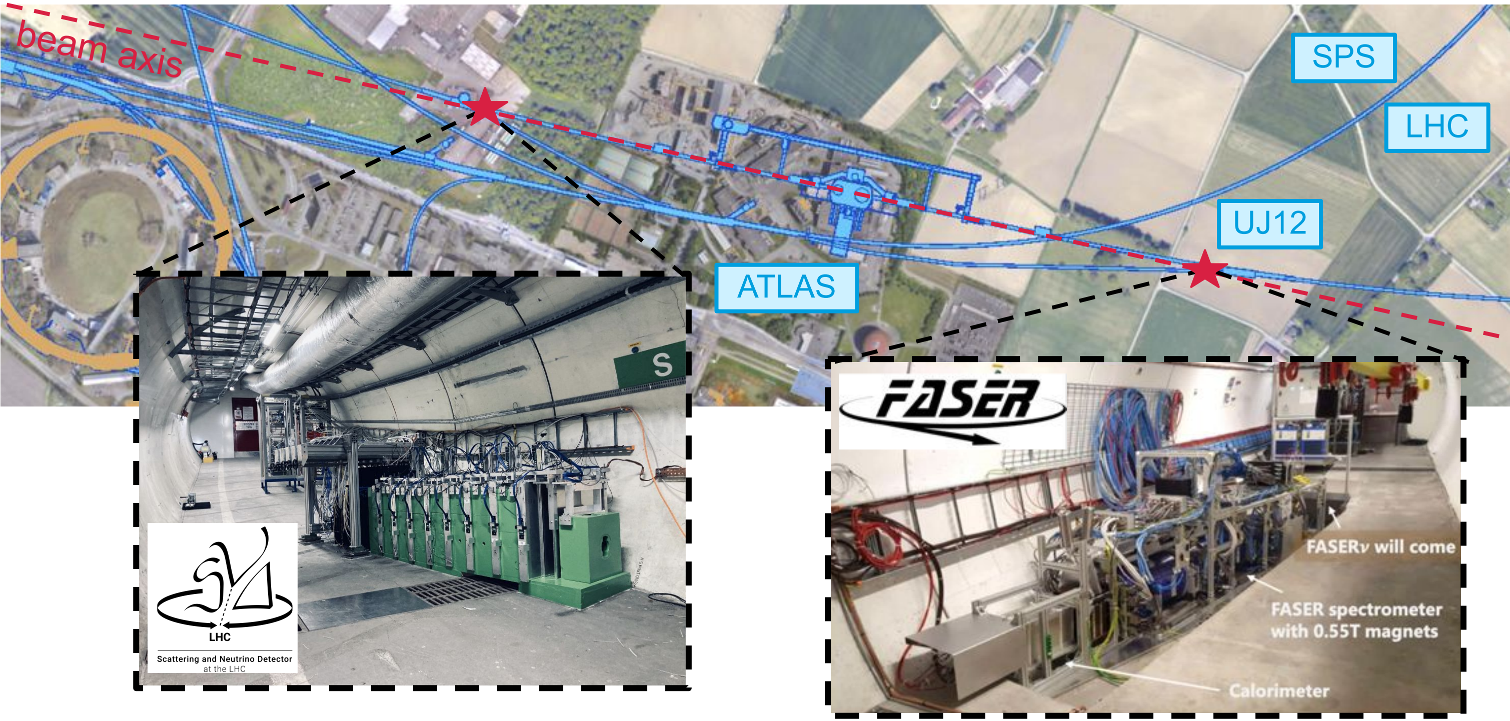


Experimental Program

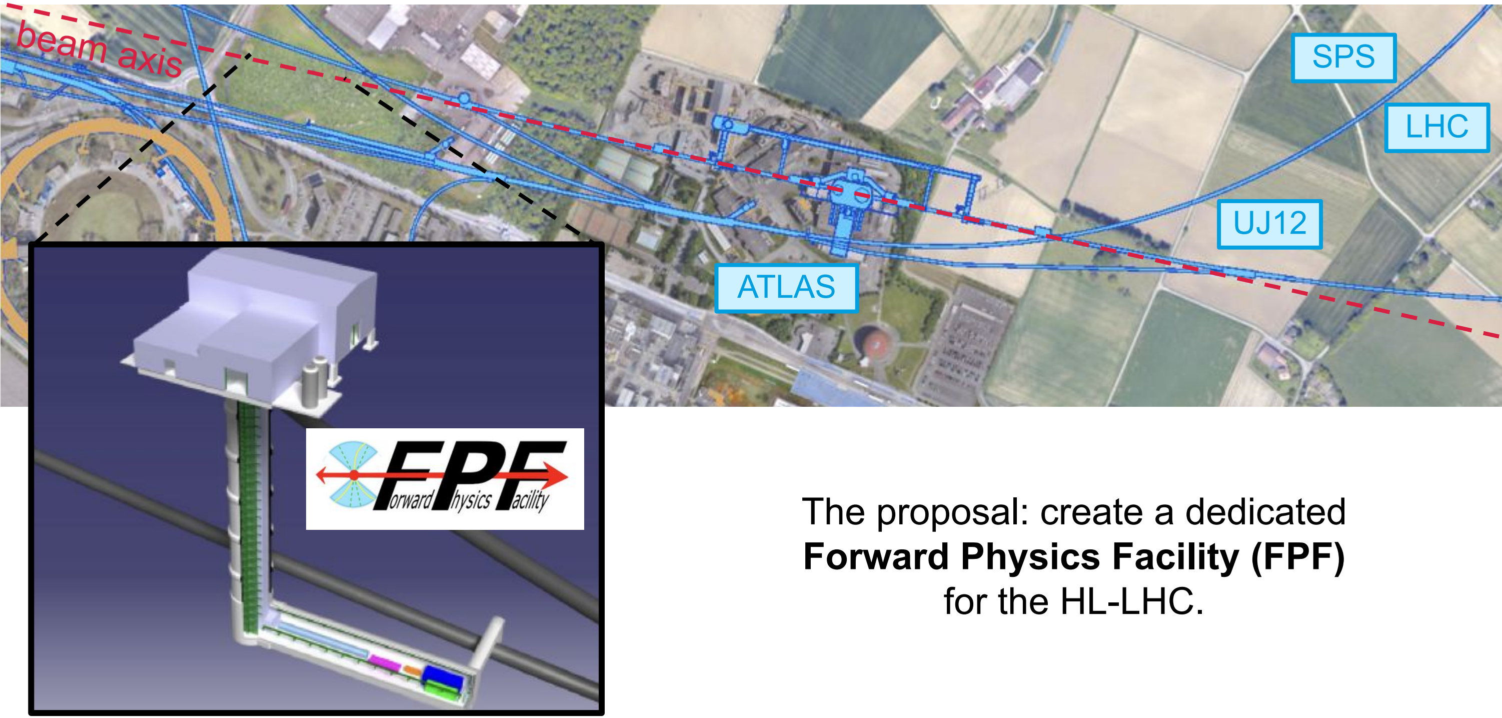
Now: FASER and SND@LHC.

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.

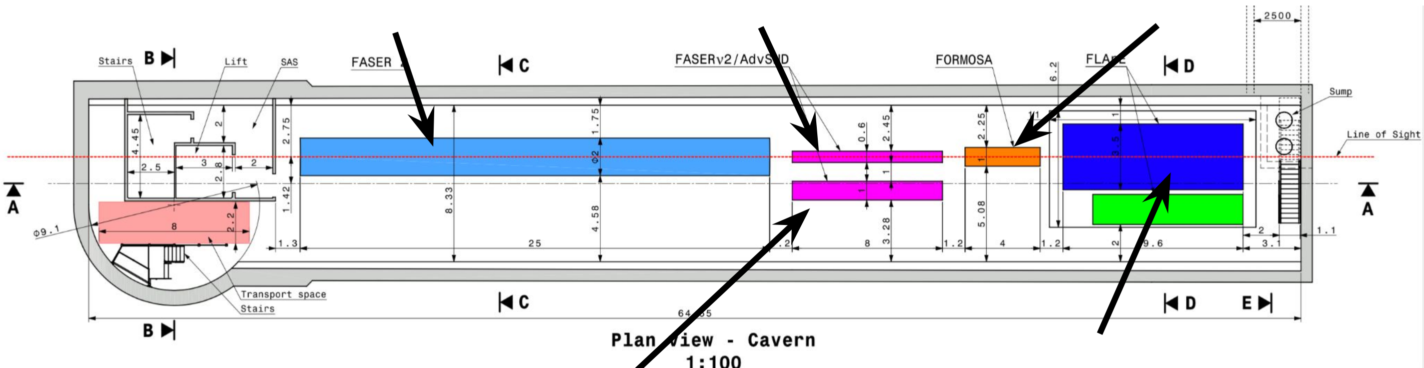
Forward Physics Facility.

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.

FASER2
magnetized spectrometer
for BSM searches

FASERν2
emulsion-based
neutrino detector

FORMOSA
plastic scintillator array
for BSM searches



AdvSND
electronic
neutrino detector

FLArE
LAr based
neutrino detector

Forward Physics Facility.

FPF workshop series:
FPF1, FPF2, FPF3, FPF4

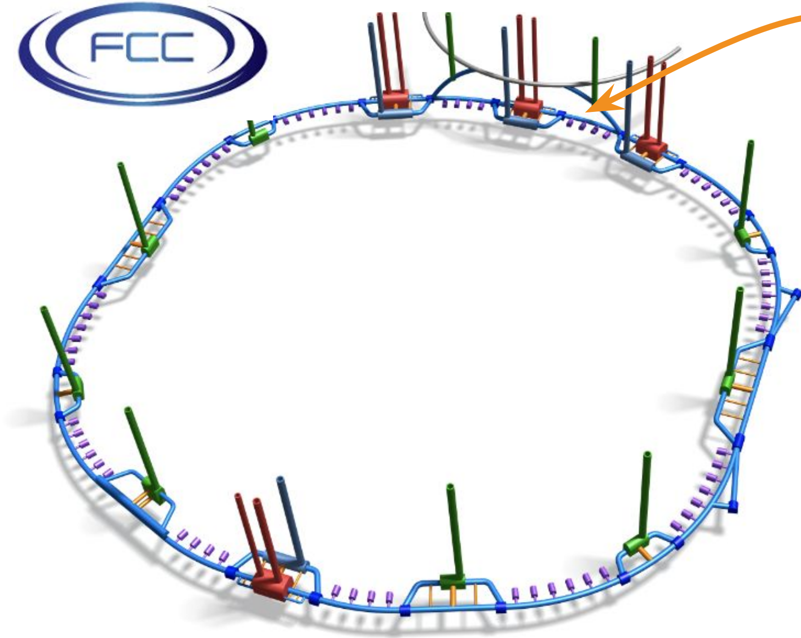
FPF Paper:
2109.10905
~75 pages, ~80 authors

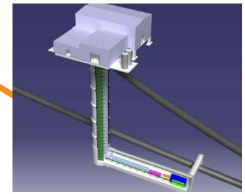
Snowmass Whitepaper:
2203.05090
~450 pages, ~250 authors

Far Future: FPF@FCC.

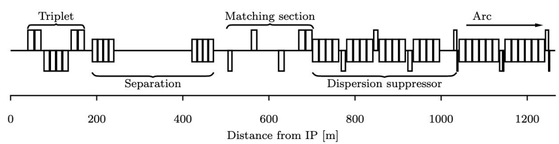
Similar experiments should also be considered for future colliders such the FCC-hh.

Dedicated facility can be included from the beginning.

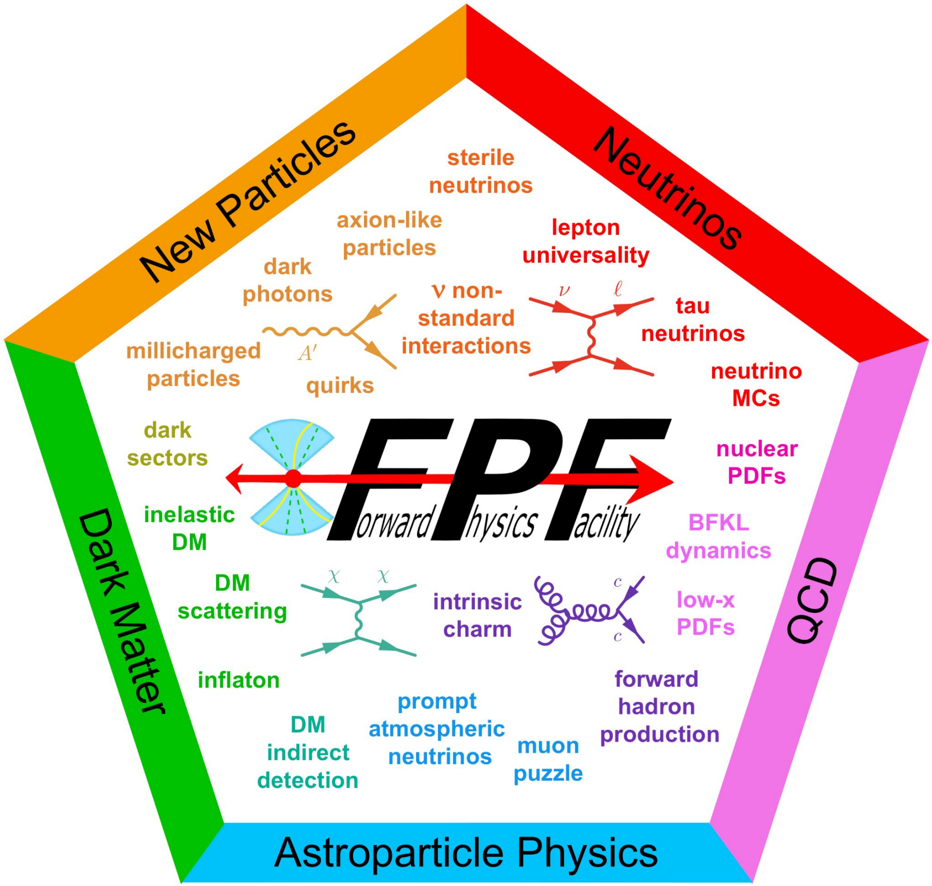




location ~1.5km downstream from IP possible 2007.12058

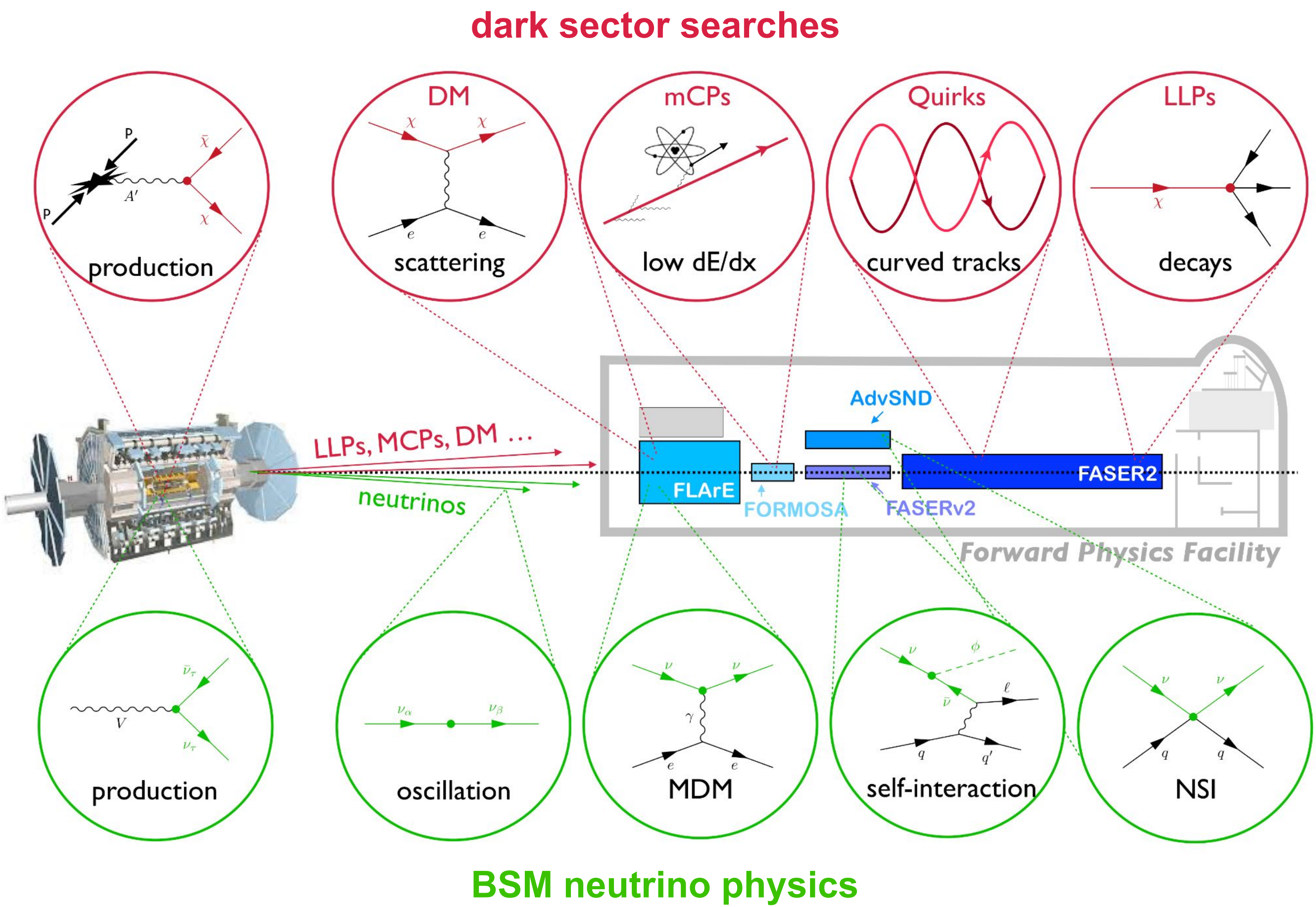


Physics Potential.



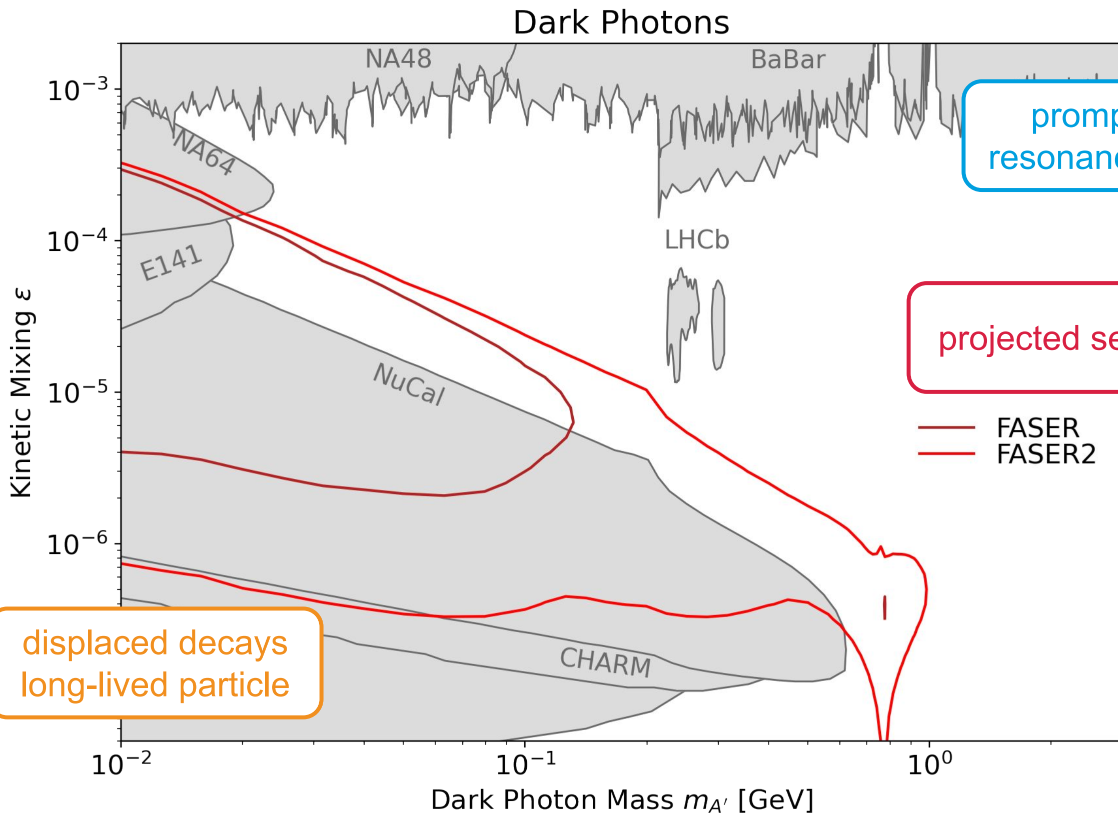
BSM Physics Searches

Searches for BSM Physics.



Long-Lived Particle Searches.

Dark Photon = gauge boson mixing with photon: $\mathcal{L} \sim -\frac{1}{2} m_{A'}{}^2 A'^2 - \epsilon e q_f \bar{f} \not{A}' f$

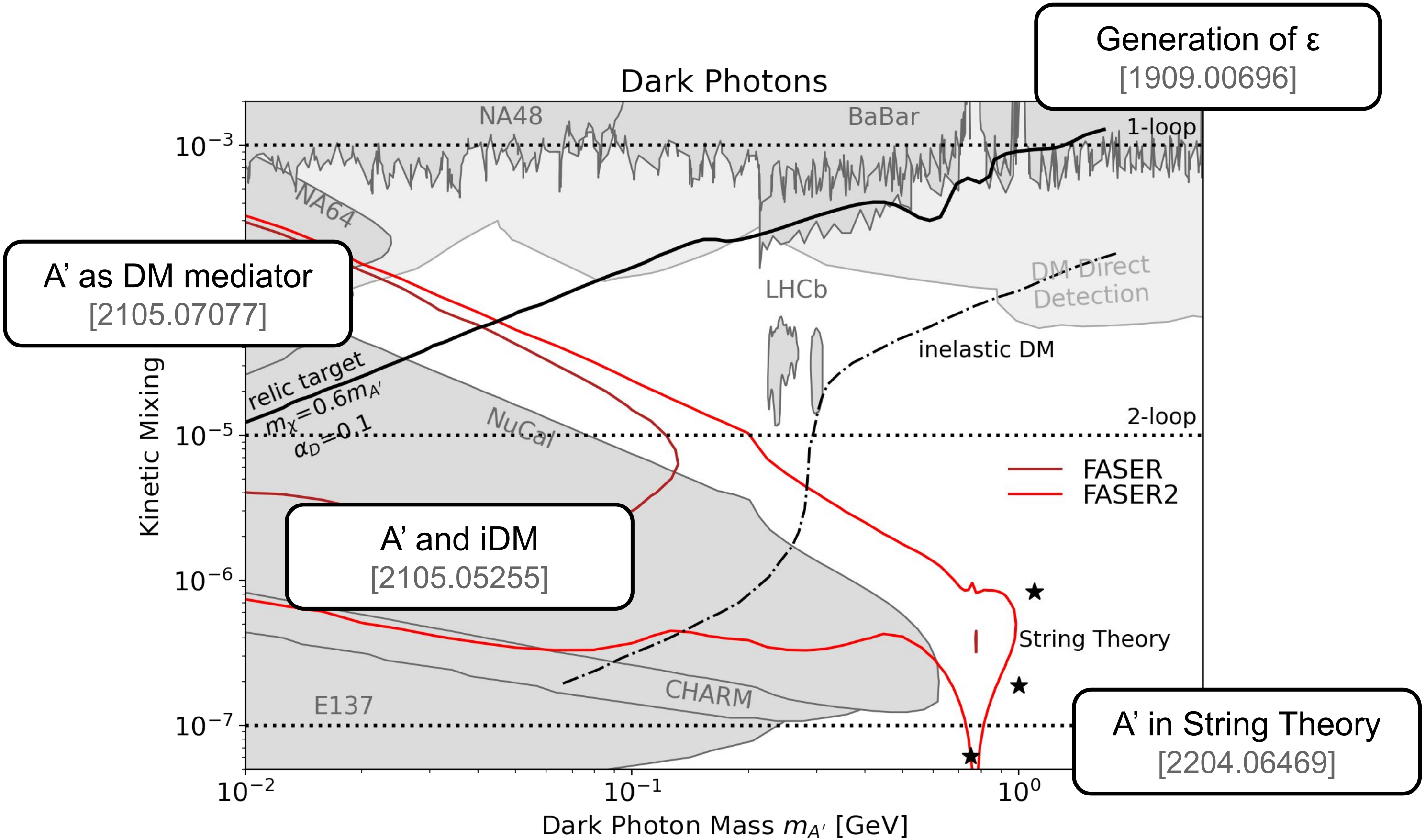


prompt decays
resonance searches

projected sensitivity

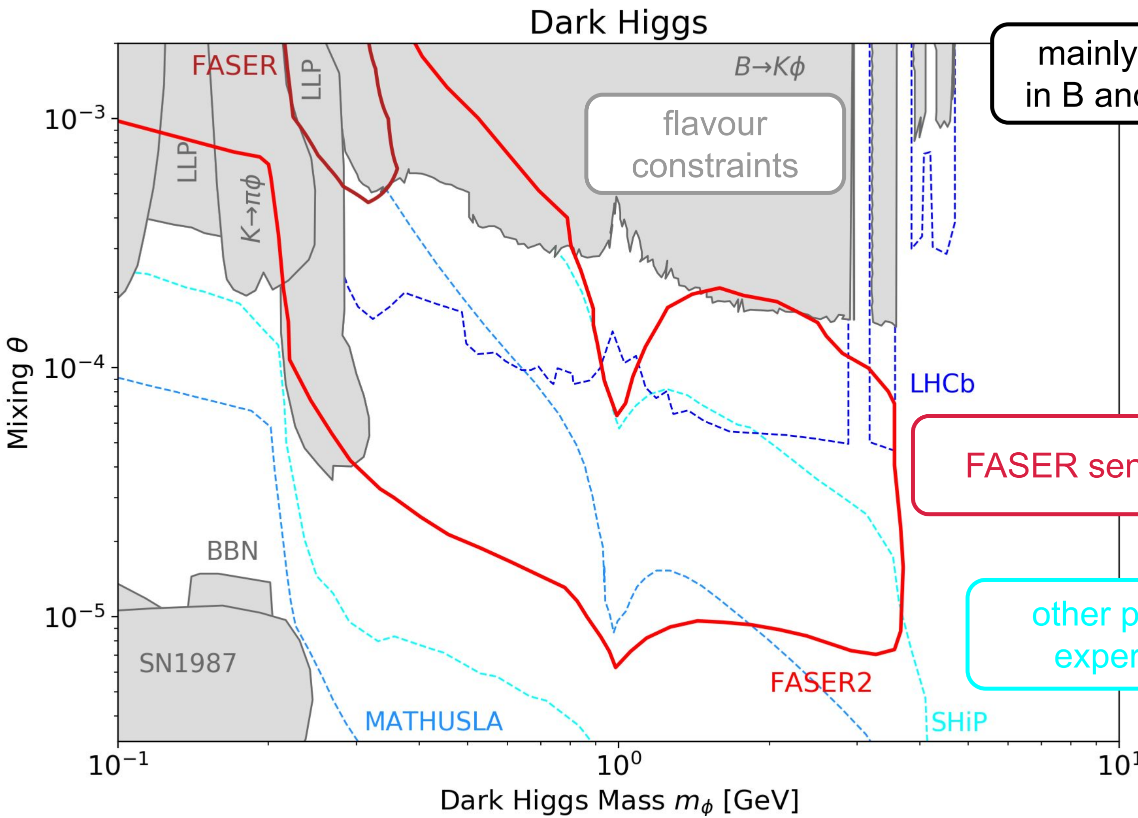
displaced decays
long-lived particle

Long-Lived Particle Searches.



Long-Lived Particle Searches.

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

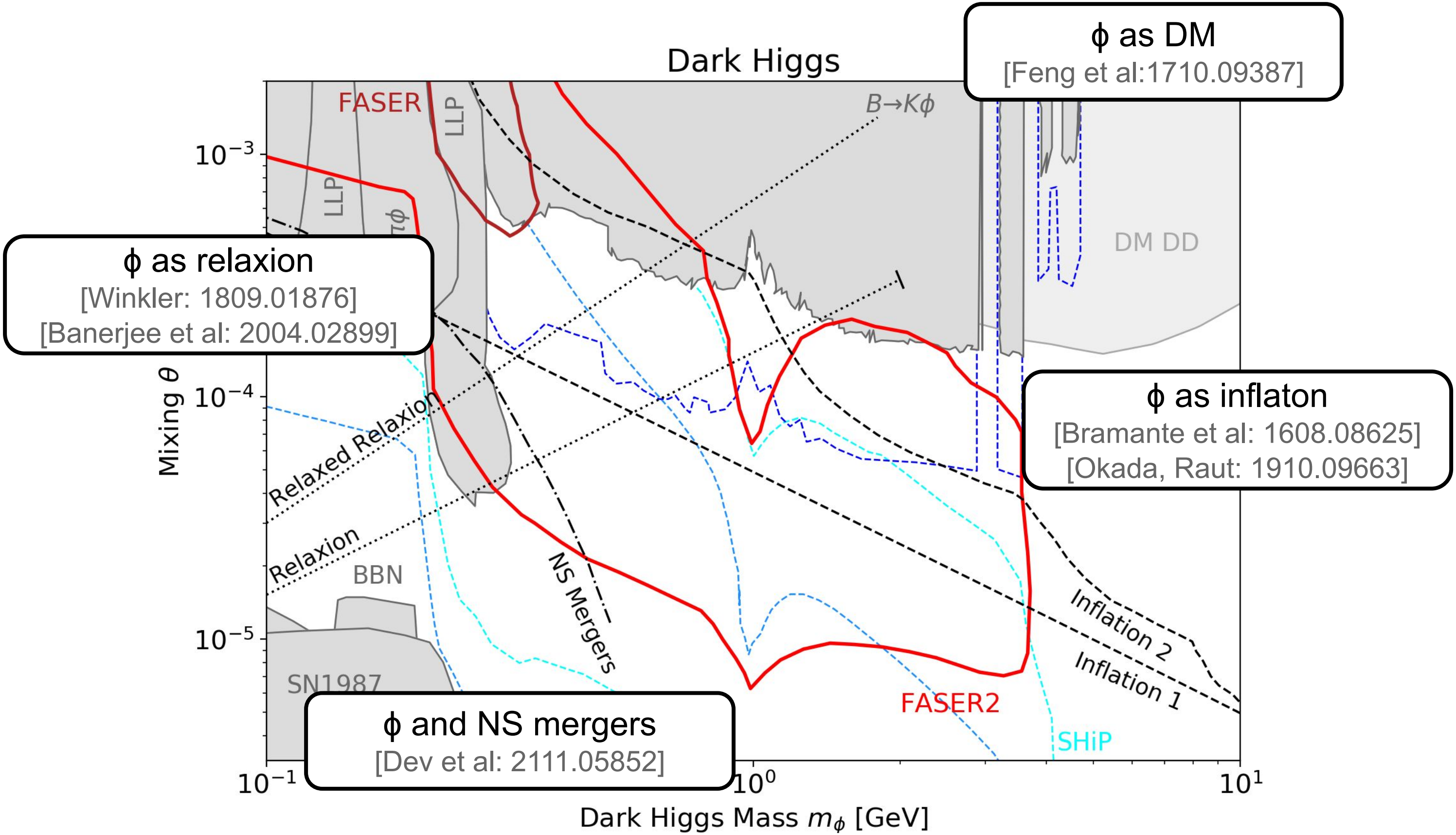


mainly produced in B and K decays

FASER sensitivity

other proposed experiments

Long-Lived Particle Searches.



Long-Lived Particle Searches.

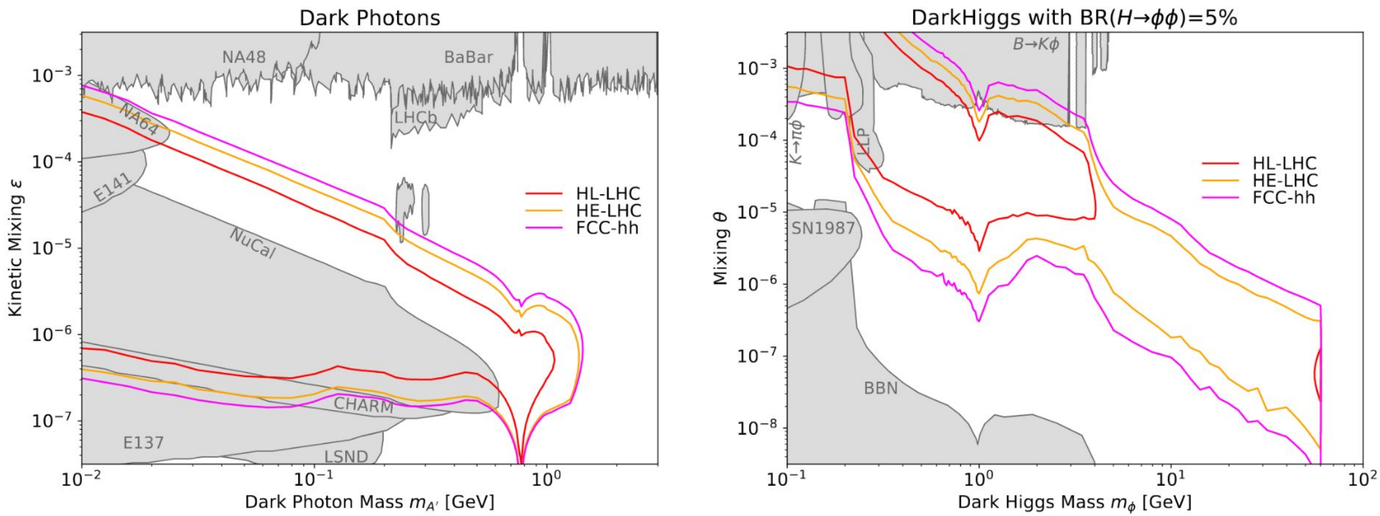
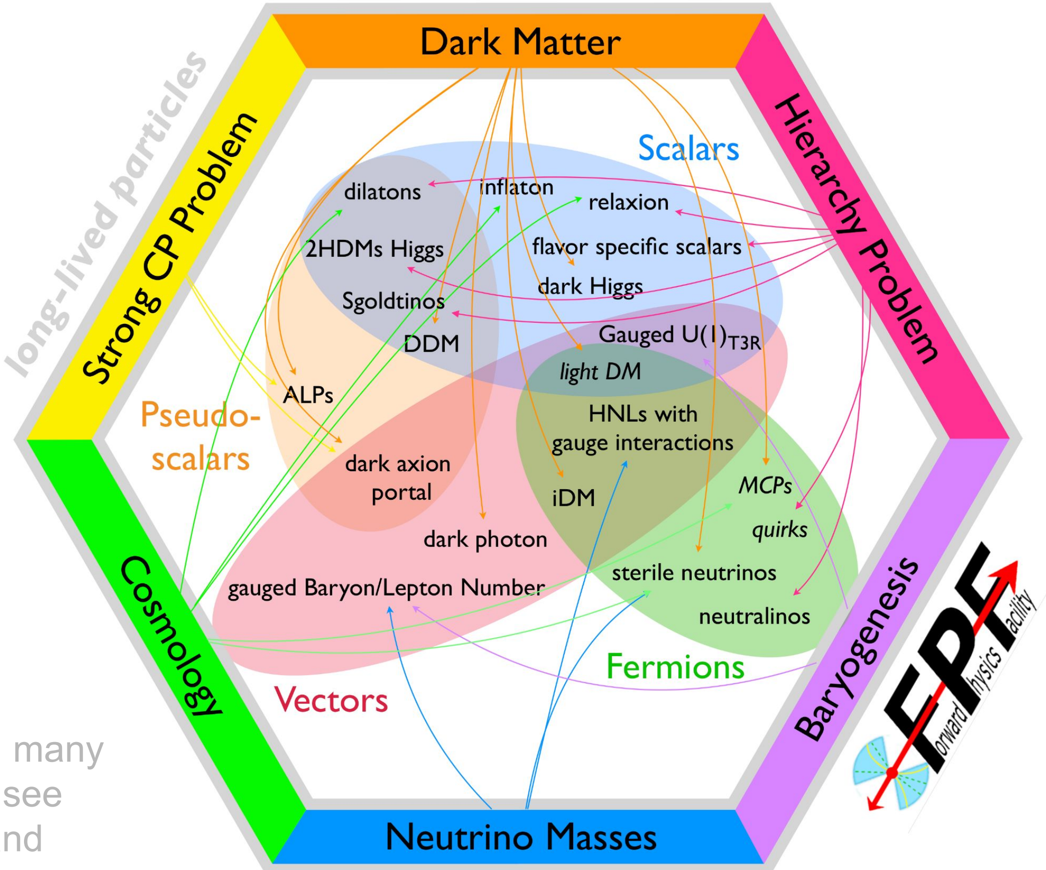


FIG. 3. Sensitivity reach lines obtained for the FASER 2 detector to take data during the HL-LHC era (red solid line) and for similar detectors operating at the future hadron colliders: HE-LHC (orange) and FCC-hh/SppC (purple). The details of the assumed detector design are given in Table II. The reach 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_ϕ, θ) plane (right). In both cases, current bounds on the model parameter space are shown with gray-shaded regions (see the text for details).

[Kling, Trojanowski: 2105.07077]

Long-Lived Particle Searches.

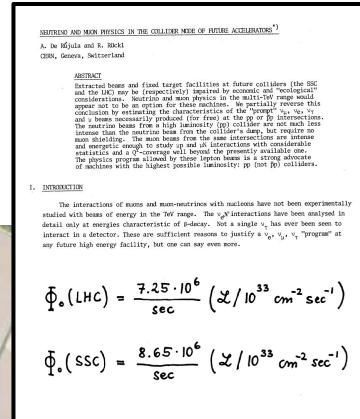


For details on many more models see [1811.12522](https://arxiv.org/abs/1811.12522) and [2203.05090](https://arxiv.org/abs/2203.05090).

SM Physics Measurements

Neutrinos at Colliders.

There is a huge flux of neutrinos in the forward direction, mainly from π, K and D meson decays.
[De Rujula et al. (1984)]



NEUTRINO AND MUON PHYSICS IN THE COLLIDER MODE OF FUTURE ACCELERATORS*)

A. De Rújula and R. Rückl
CERN, Geneva, Switzerland

ABSTRACT

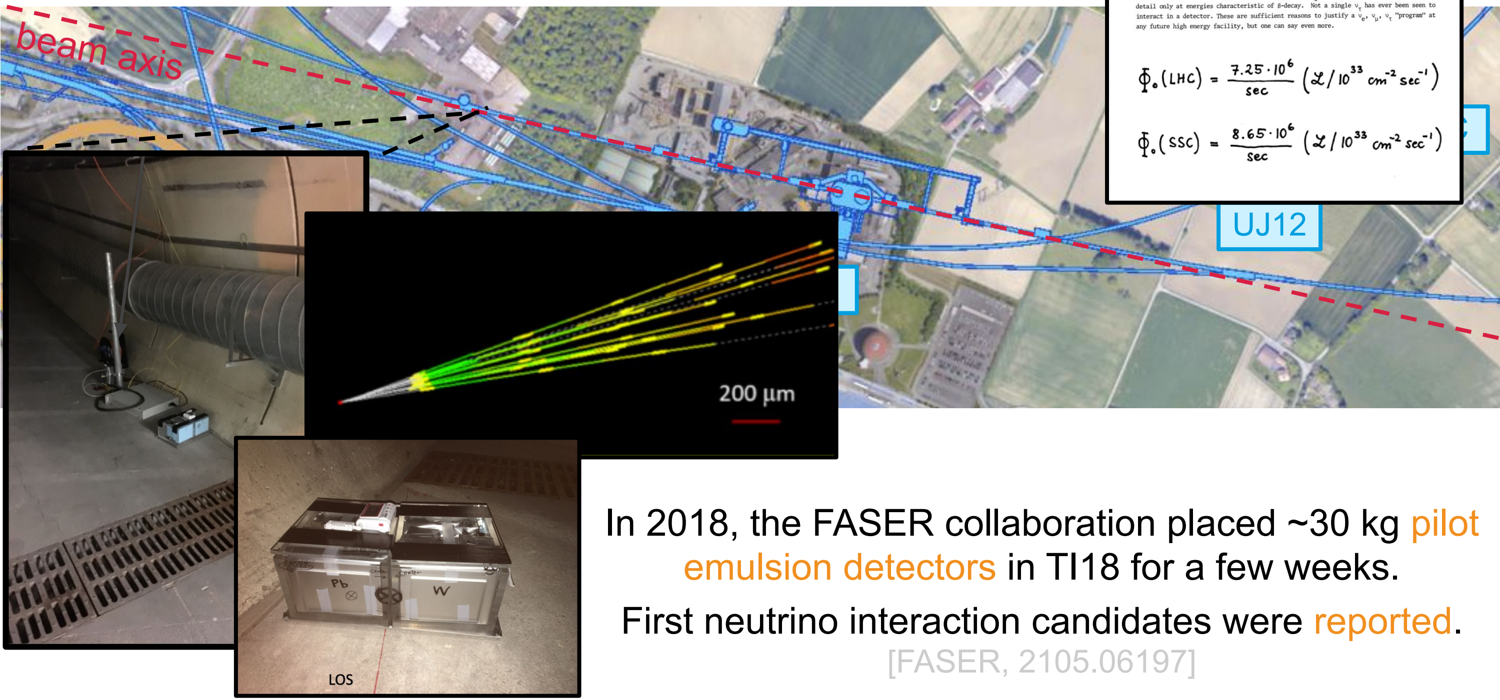
Extracted beams and fixed target facilities at future colliders (the SSC and the LHC) may be (respectively) impaired by economic and "ecological" considerations. Neutrino and muon physics in the multi-TeV range would appear not to be an option for these machines. We partially reverse this conclusion by estimating the characteristics of the "prompt" ν_μ, ν_e, ν_τ and μ beams necessarily produced (for free) at the pp or $\bar{p}p$ intersections. The neutrino beams from a high luminosity (pp) collider are not much less intense than the neutrino beam from the collider's dump, but require no muon shielding. The muon beams from the same intersections are intense and energetic enough to study μp and μN interactions with considerable statistics and a Q^2-coverage well beyond the presently available one. The physics program allowed by these lepton beams is a strong advocate of machines with the highest possible luminosity: pp (not $\bar{p}p$) colliders.

I. INTRODUCTION

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

$$\Phi_0(LHC) = \frac{7.25\cdot 10^6}{sec}\left(\mathcal{L}/10^{33}\ cm^{-2}\ sec^{-1}\right)$$

$$\Phi_0(SSC) = \frac{8.65\cdot 10^6}{sec}\left(\mathcal{L}/10^{33}\ cm^{-2}\ sec^{-1}\right)$$



In 2018, the FASER collaboration placed ~30 kg pilot emulsion detectors in TI18 for a few weeks.

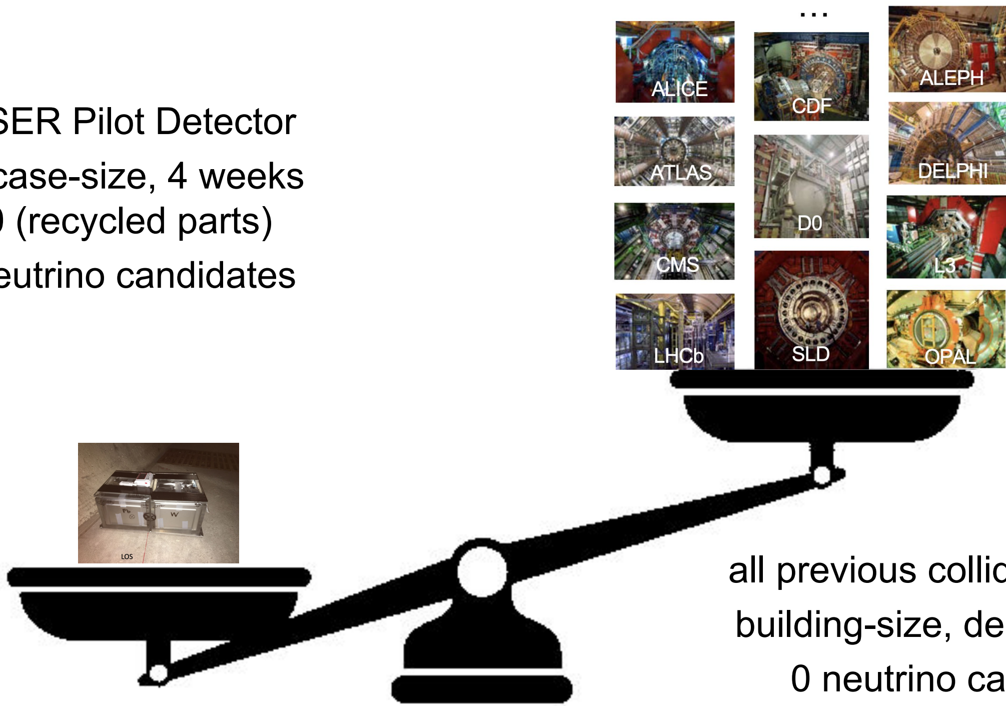
First neutrino interaction candidates were reported.
[FASER, 2105.06197]

Neutrinos at Colliders.

FASER Pilot Detector

suitcase-size, 4 weeks
$0 (recycled parts)

6 neutrino candidates



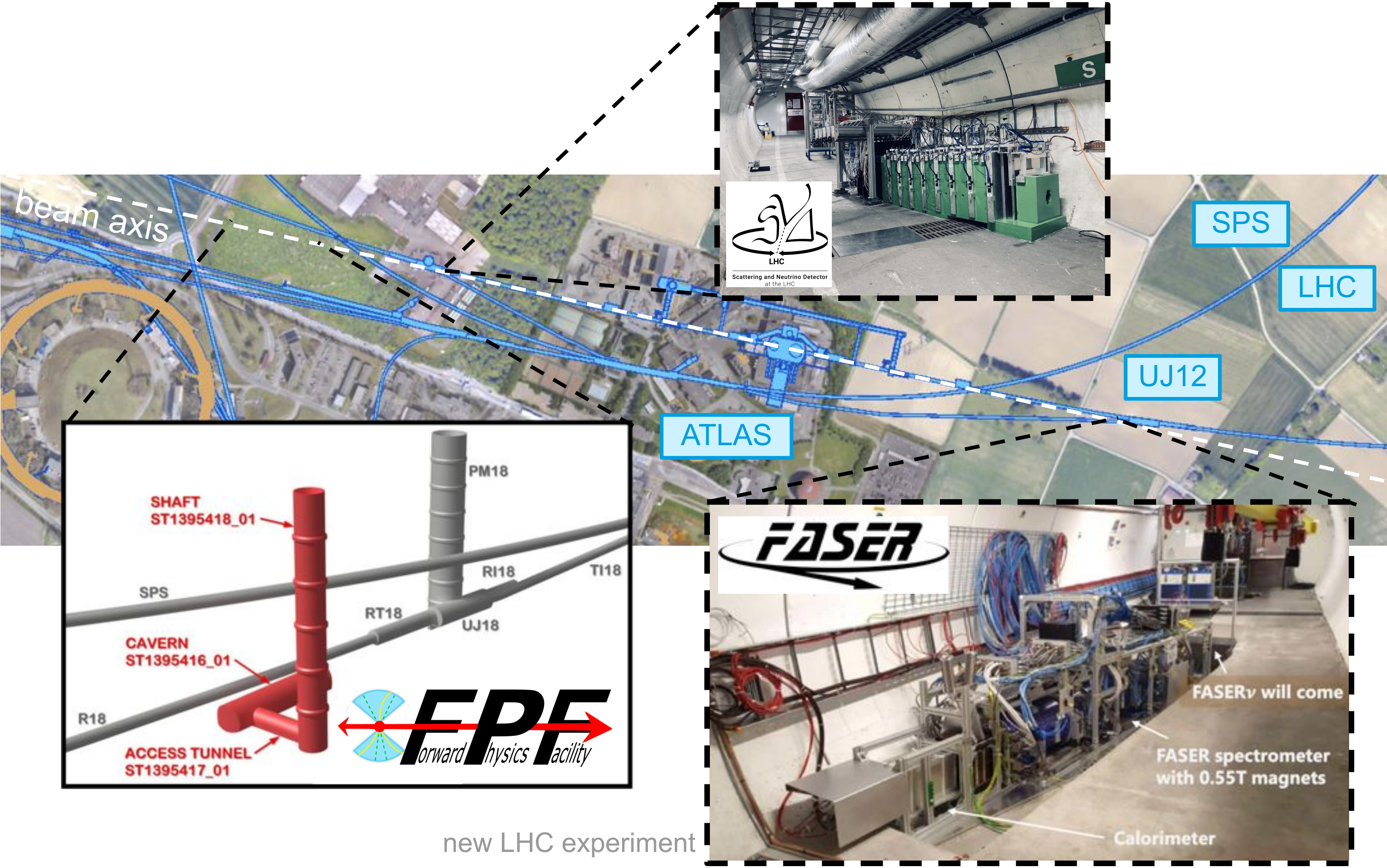
all previous collider detectors

building-size, decades ~$1B

0 neutrino candidates

slide by Jonathan Feng

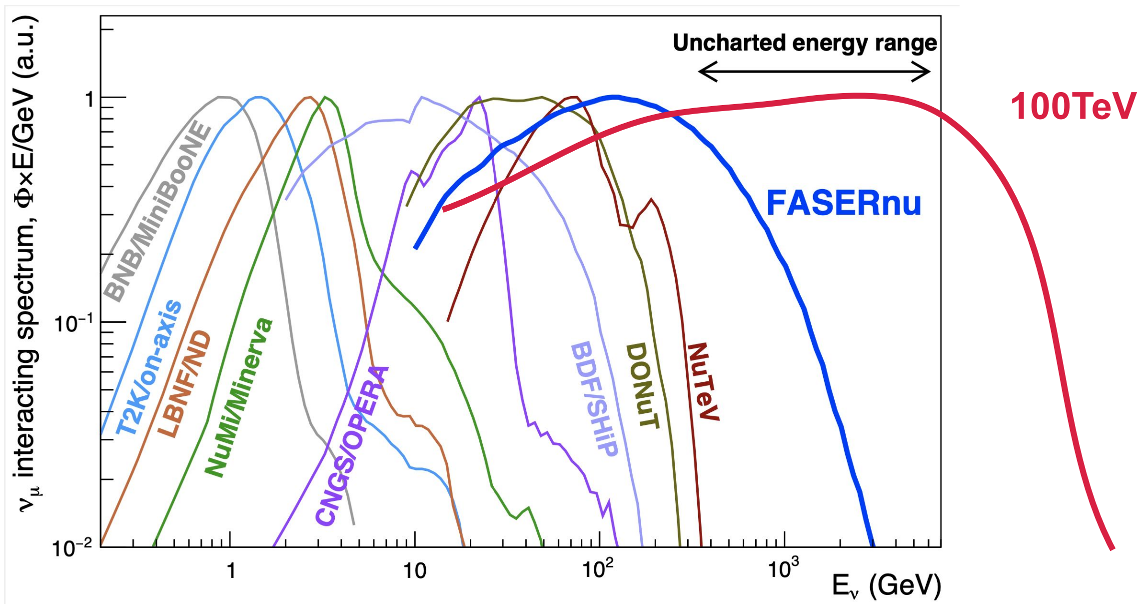
Neutrinos at Colliders.



new LHC experiment

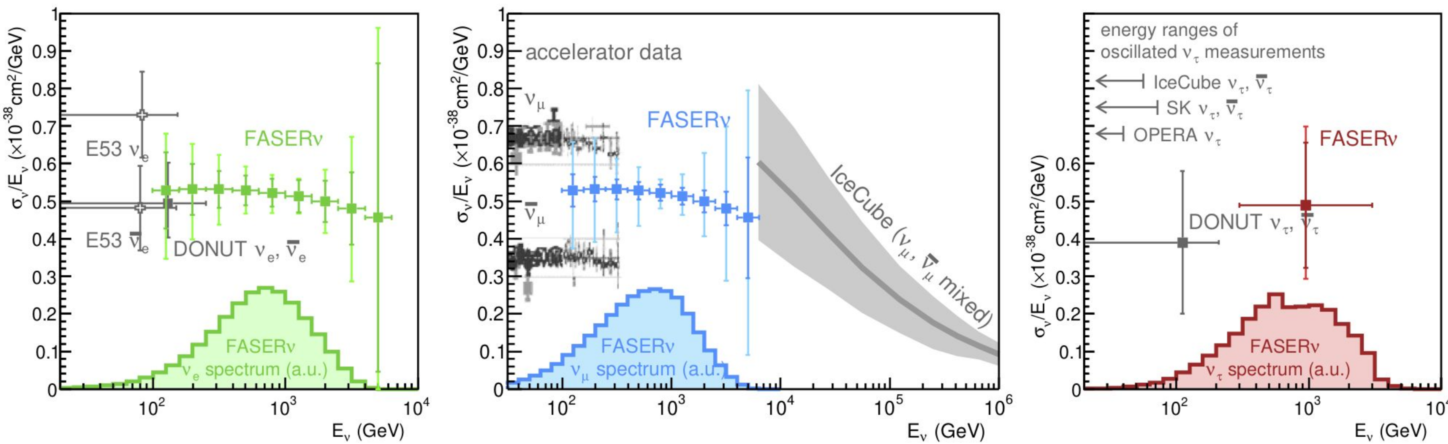
Neutrinos at Colliders.

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.

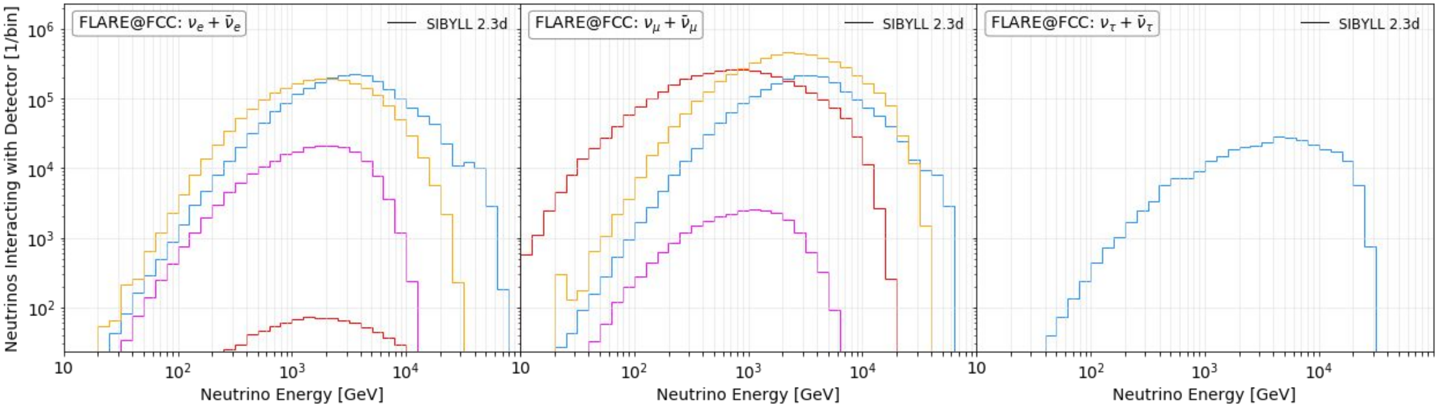


FASERν and SND@LHC will detect O(10k) neutrinos.
(including 10s of tau neutrinos)

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

Neutrinos Physics

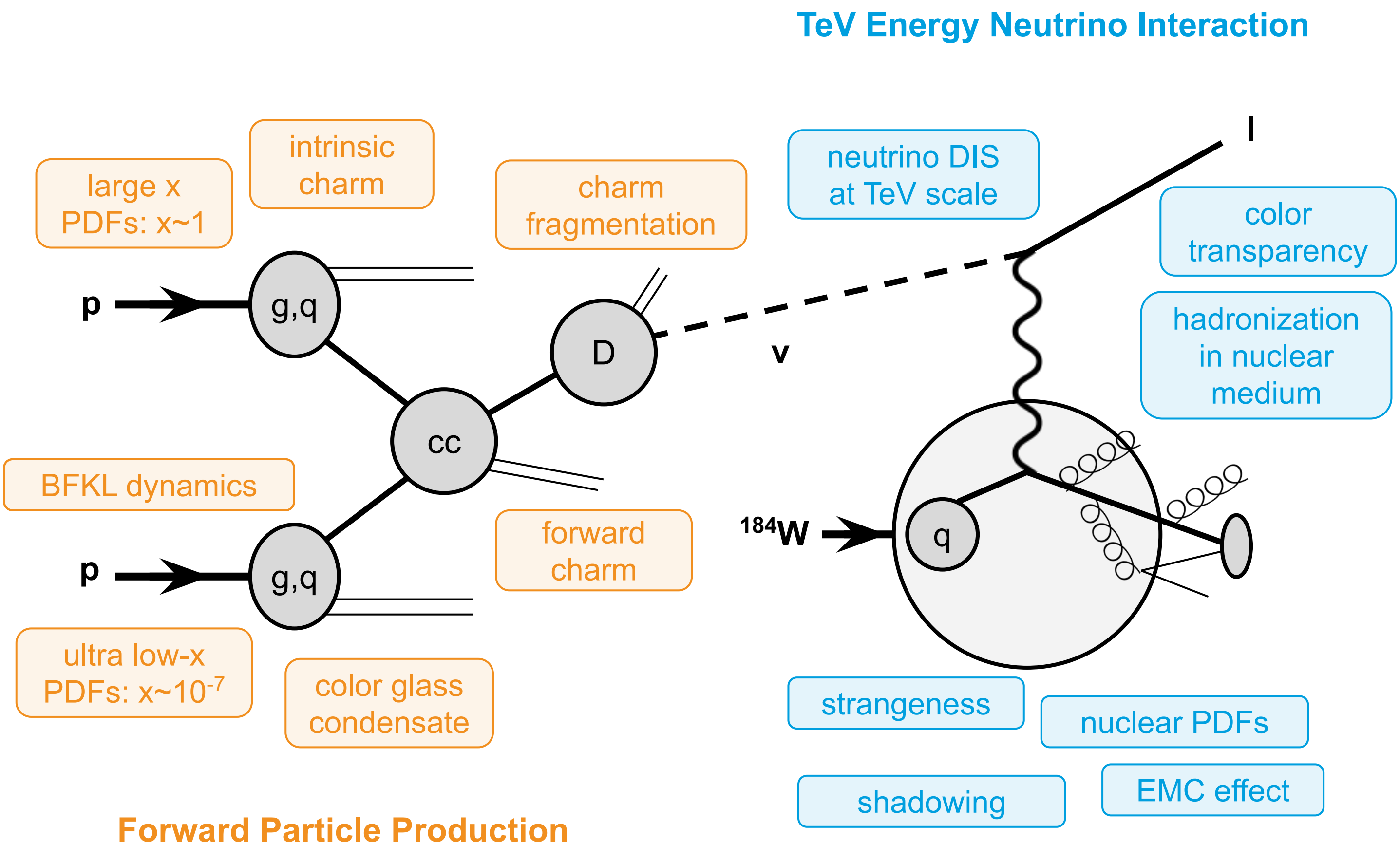
neutrino flux estimating using fast simulation and geometry from 2007.12058



15M/10ton 9M/10ton 300k/10ton

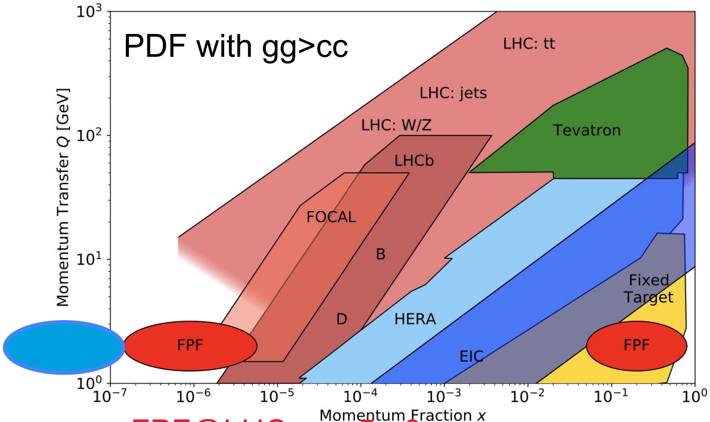
bigger target masses of up to kton could be possible (NuTeV was 0.7kton)
→ 30M tau neutrinos

QCD.



TeV Energy Neutrino Interaction
large x
PDFs: x~1
intrinsic
charm
charm
fragmentation
neutrino DIS
at TeV scale
l
color
transparency
p
g,q
D
v
hadronization
in nuclear
medium
cc
BFKL dynamics
forward
charm
184W
q
p
g,q
ultra low-x
PDFs: x~10-7
color glass
condensate
strangeness
nuclear PDFs
shadowing
EMC effect
Forward Particle Production

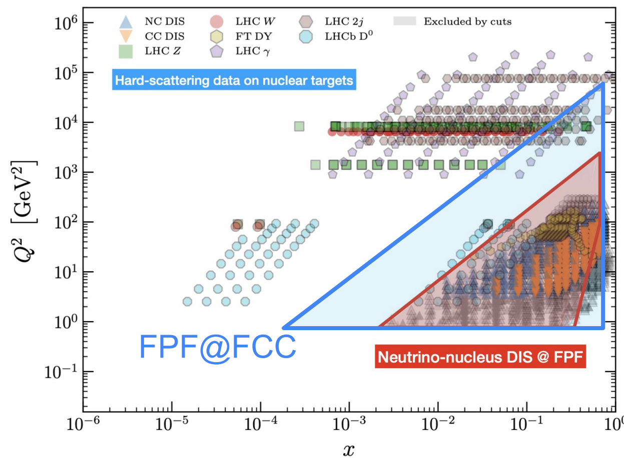
FPF @ Future Colliders.



FPF@LHC: x > 5e-8

FPF@FCC: x > 9e-10

PDF via ν-scattering: x ~ 1/Eν

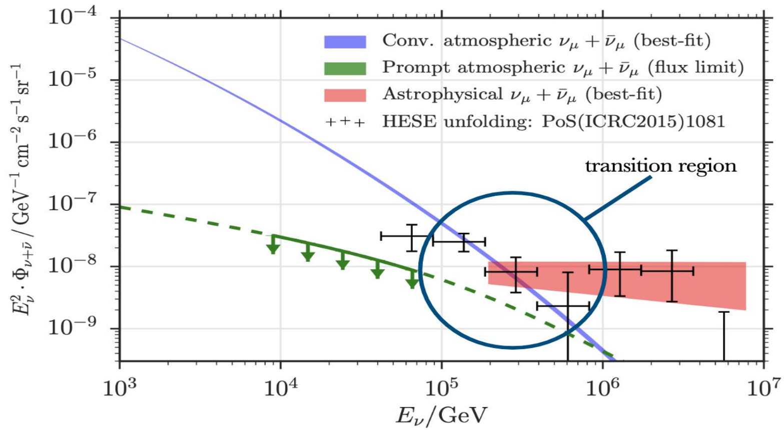


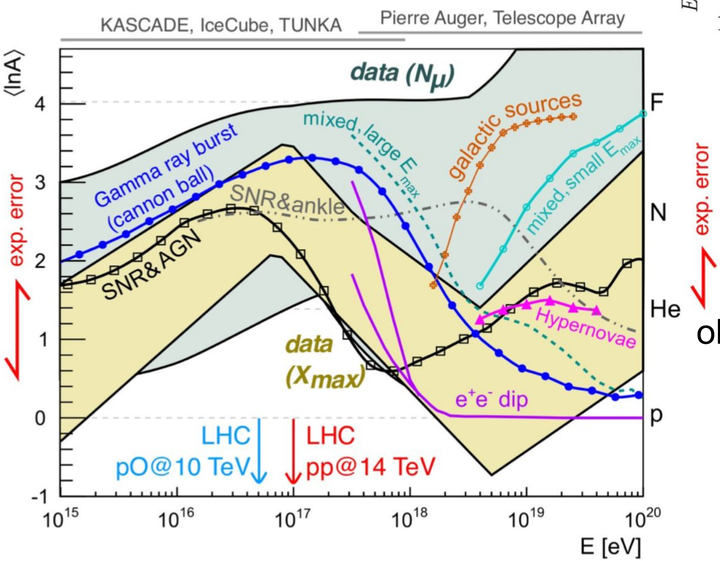
Astroparticle Physics.

forward charm production at the LHC

↓

constraints on prompt atmospheric neutrino flux at IceCube





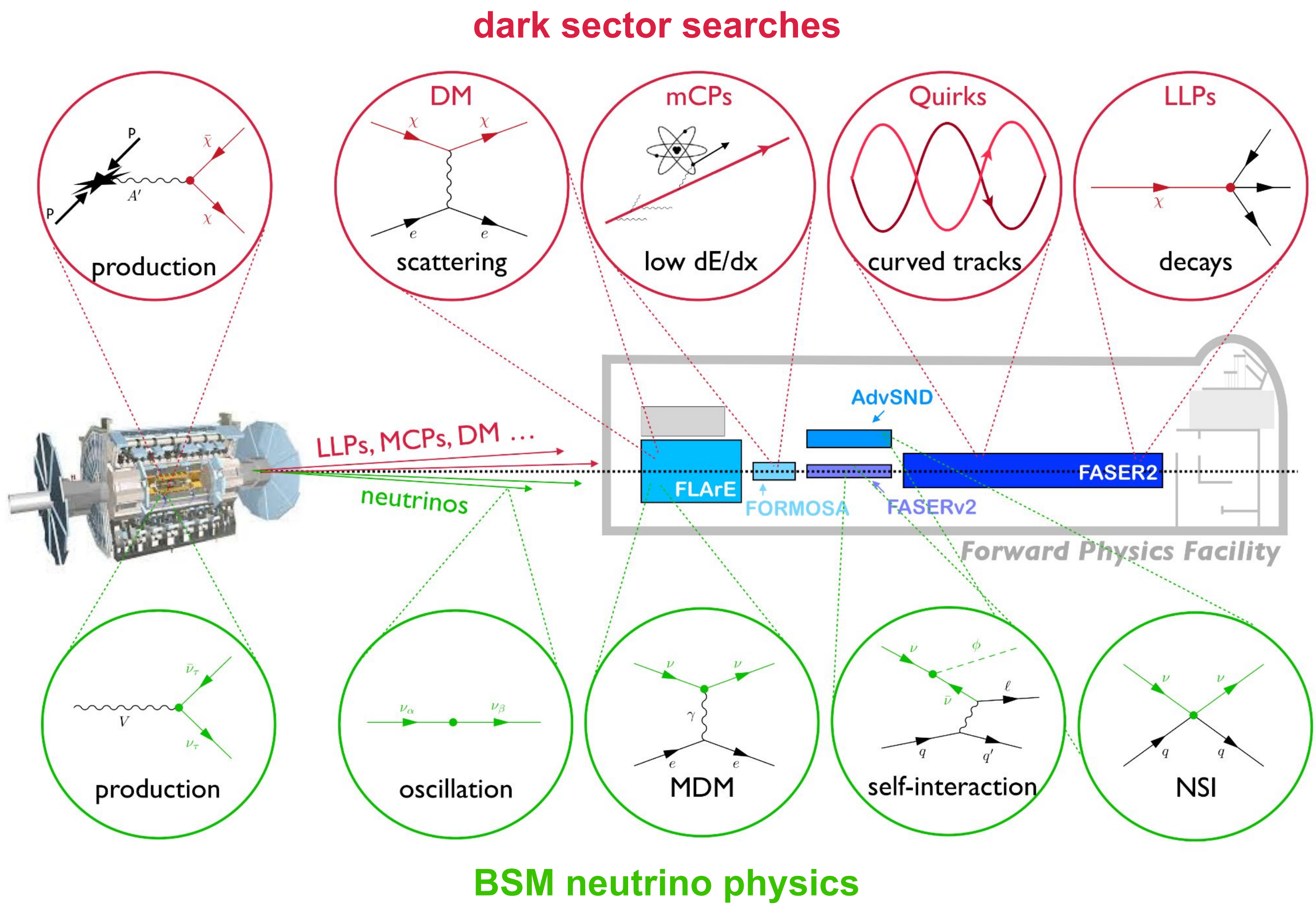
cosmic ray muon puzzle:

observed excess of muons compared to hadronic interaction models

forward pion/kaons fluxes will provide crucial input

Based on Kampert & Unger, Astropart. Phys. 35 (2012) 660

Searches for BSM 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!