Bremming Enhanced ALP Productions and FPF Sensitivity

4th Forward Physics Facility Meeting

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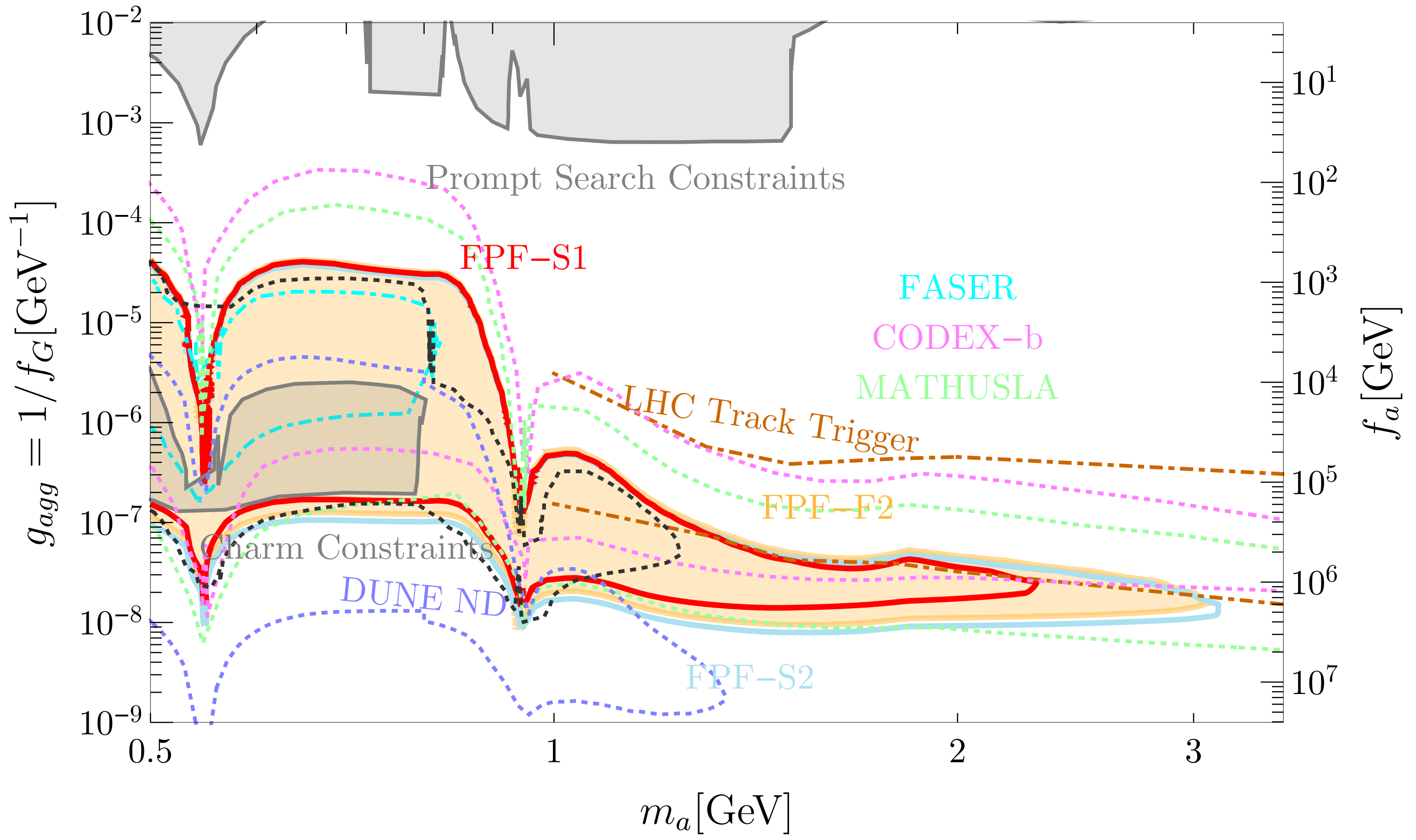
Paper in preparation
Contribution to FPF whitepaper

ALP Search at FPF

FPF provides a good platform for detecting the LLP in the very forward region.

Axion or Axion-like particle (ALP) solves the strong CP problem, good candidates for dark matter.



Heavy ALP
Mass around GeV

Enhance FASER and FASER2 projection

Complementary to other experiments

ALP Production at LHC

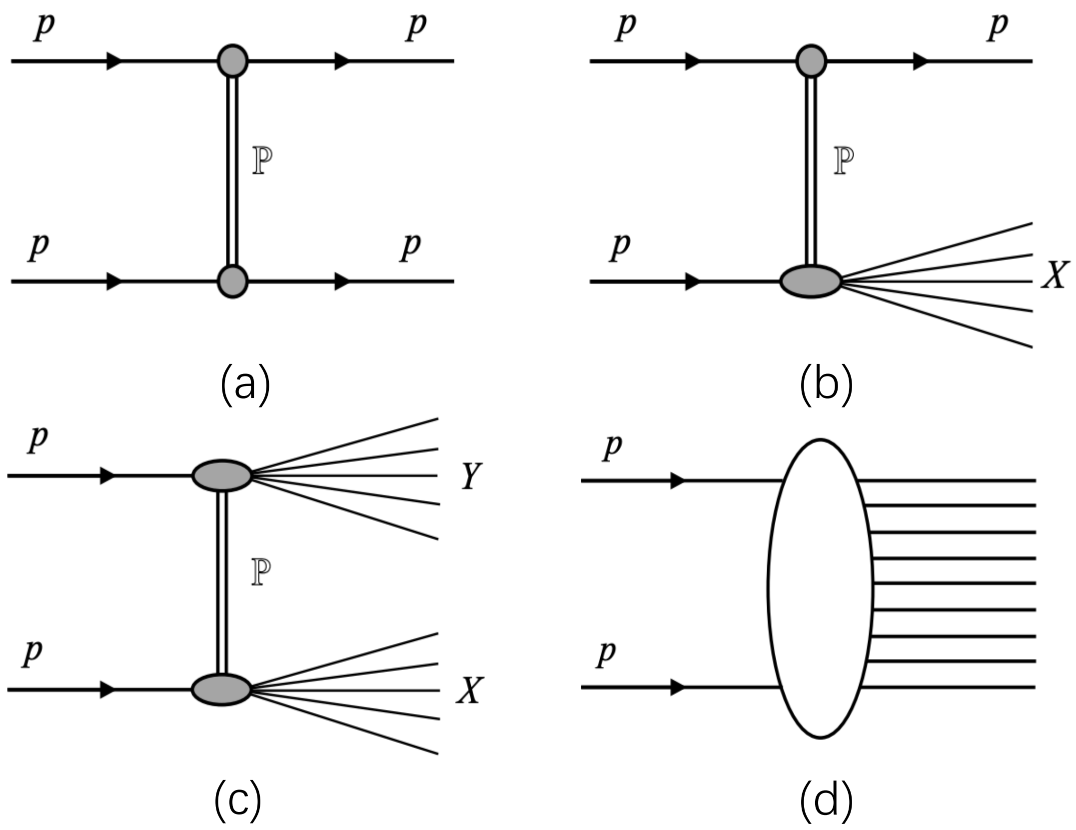
Mixing with Mesons, Hard Scattering

Bremsstrahlung

$$\frac{a}{8\pi f_a}\left(c_3\alpha_3 G\tilde{G} + c_2\alpha_2 W\tilde{W} + c_1\alpha_1 B\tilde{B}\right)$$

Gluon Dominated Region

Proton-Proton Scattering



(a) Elastic Scattering

(b) Single Diffractive Scattering

(c) Double Diffractive Scattering

(d) Non-Diffractive Scattering

Particle Data Group (PDG) Prog. Theor. Exp. Phys. 2020, 083C01 (2020)
Foroughi-Abari et al 2108.05900

We focus on the ALP as initial state radiation (ISR).

ISR from partons, proton?

Parton bremming

Our (preliminary) result shows that the ISR signal from gluon and quark bremming far smaller than the parton bremming

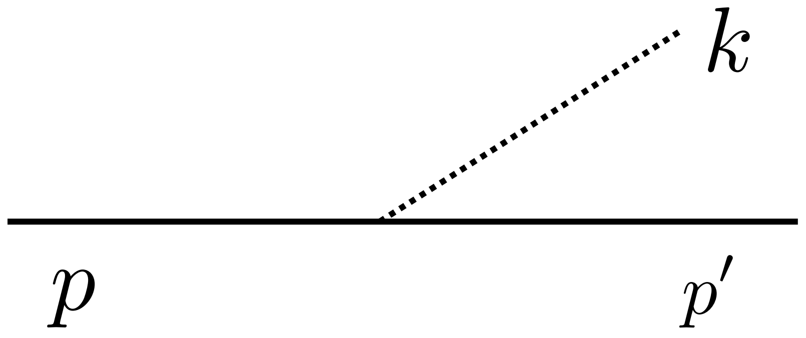
Proton bremming

Primary contribution.

Splitting Function

The signal rate for emitting an axion from the proton bremming

$$\sigma = \int dz dp_T^2 \frac{d\mathcal{P}}{dz dp_T^2} \hat{\sigma}_{\rm NSD}(\hat{s})$$



$$\frac{d\mathcal{P}}{dz dp_T^2} = \frac{1}{16\pi^2} \frac{z}{1-z} \frac{1}{(p'^2 - m_p^2)^2} \left[\frac{1}{2}\sum |\mathcal{M}|^2\right] F_S(k,p')^2$$

Hadronic Form Factor

$$F_S(k,p') = F_{1,p}^a(k^2) F_{pp^*a}(p'^2)$$

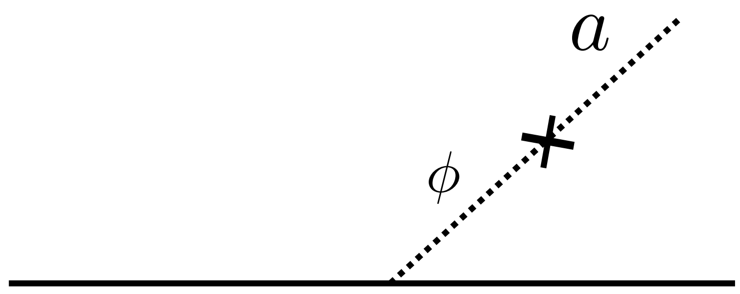
$$F_{pp^*a}(p'^2) = \frac{\Lambda^4}{\Lambda^4 + (p'^2 - m_p^2)^2} \qquad \Lambda = 1 \sim 2\,\text{GeV}$$

Structure Form Factor

Effective operator $\frac{C_p(m_a)}{2f_a}\bar{p}\gamma^\mu\gamma_5 p\,\partial_\mu a$

$$C_p(m_a) = C_p^0 + \sum_\phi \frac{C_{K,\phi} m_a^2}{m_a^2 - m_\phi^2}\frac{g_{\phi pp}}{m_p} - \sum_\phi \frac{C_{M,\phi} m_\phi^2}{m_a^2 - m_\phi^2}\frac{g_{\phi pp}}{m_p}$$

Kinetic mixing Mass mixing



$C_{K,\phi}$ $C_{M,\phi}$ can be determined by the ChPT computation

$m_a \ll m_{\pi^0}$ $C_p \to 0.47$

Scenario 1:

$|C_p^0| \approx 0.47$ ignore the mixing Conservative!

Scenario 2:

$|C_p^0| \approx 0$ $g_{\pi^0 pp} = g_{\eta pp} = g_{\eta' pp}$ Approximately show the mixing effects

ALP Detection at FPF

After production at LHC, the ALP would propagate while decay

$$N_d = \int d\sin\theta_a dE_a \frac{dN_0}{dE_a d\sin\theta_a} \exp\left(-\frac{Dm_a}{\sqrt{E_a^2 - m_a^2}c\tau(m_a)}\right)\left[1 - \exp\left(-\frac{Lm_a}{\sqrt{E_a^2 - m_a^2}c\tau(m_a)}\right)\right]$$

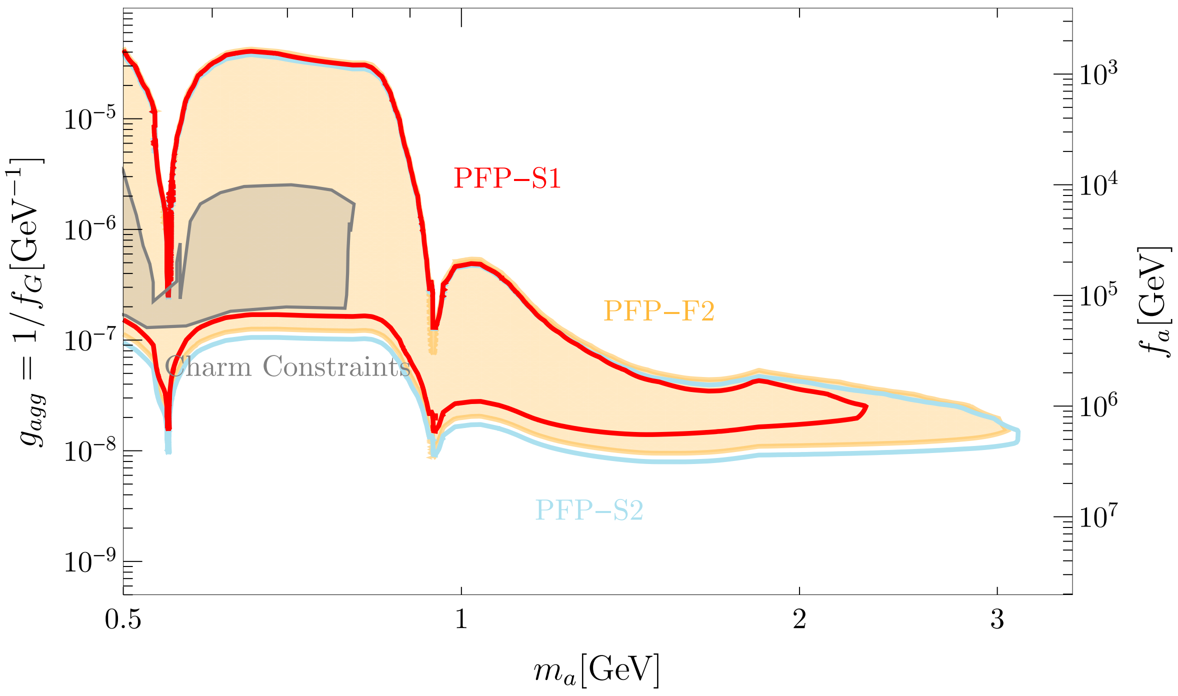
Production distribution

Decay behavior

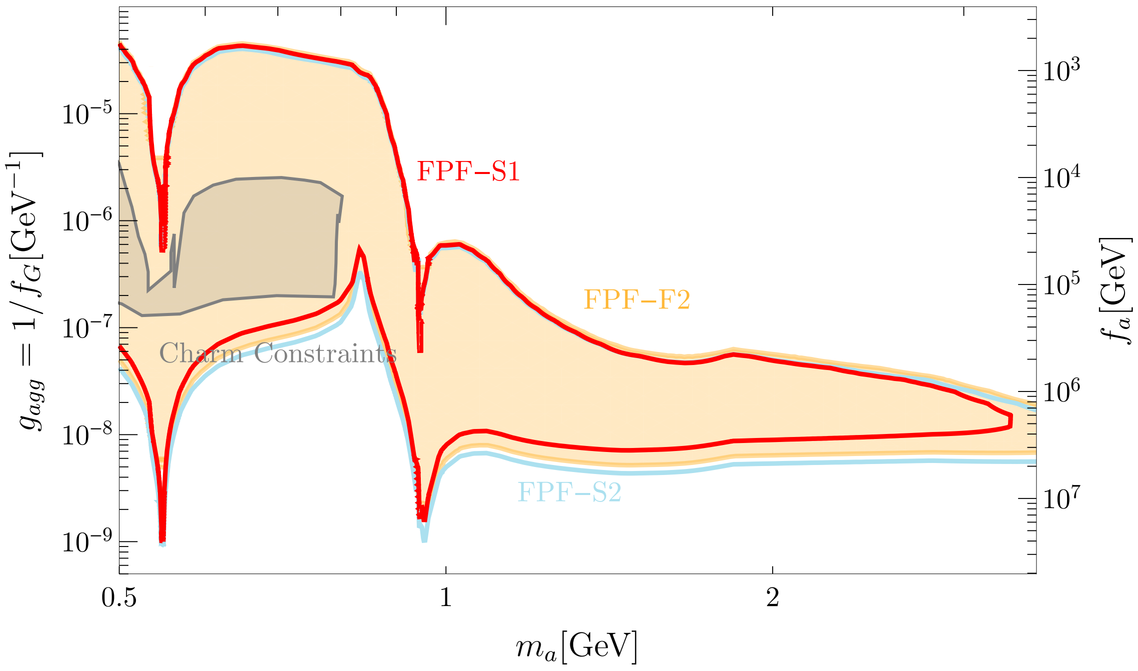
FPF Scenario	Distance to IP [m]	Available Length [m]	Decay Volume Length [m]	Available Diameter [m]	Decay Volume Diameter [m]
F2: Original FASER2	480	15	5	2	2 (/ 1 / 0.5)
S1: UJ12 Alcoves	500	5	1.5 (/ 2)	1.52	2 / 1 (/ 0.5)
S2: Purpose-Built Facility	620	25	10 (/ 15 / 20)	2	2 / 1 (/ 0.5)

FPF white paper, 2109.10905

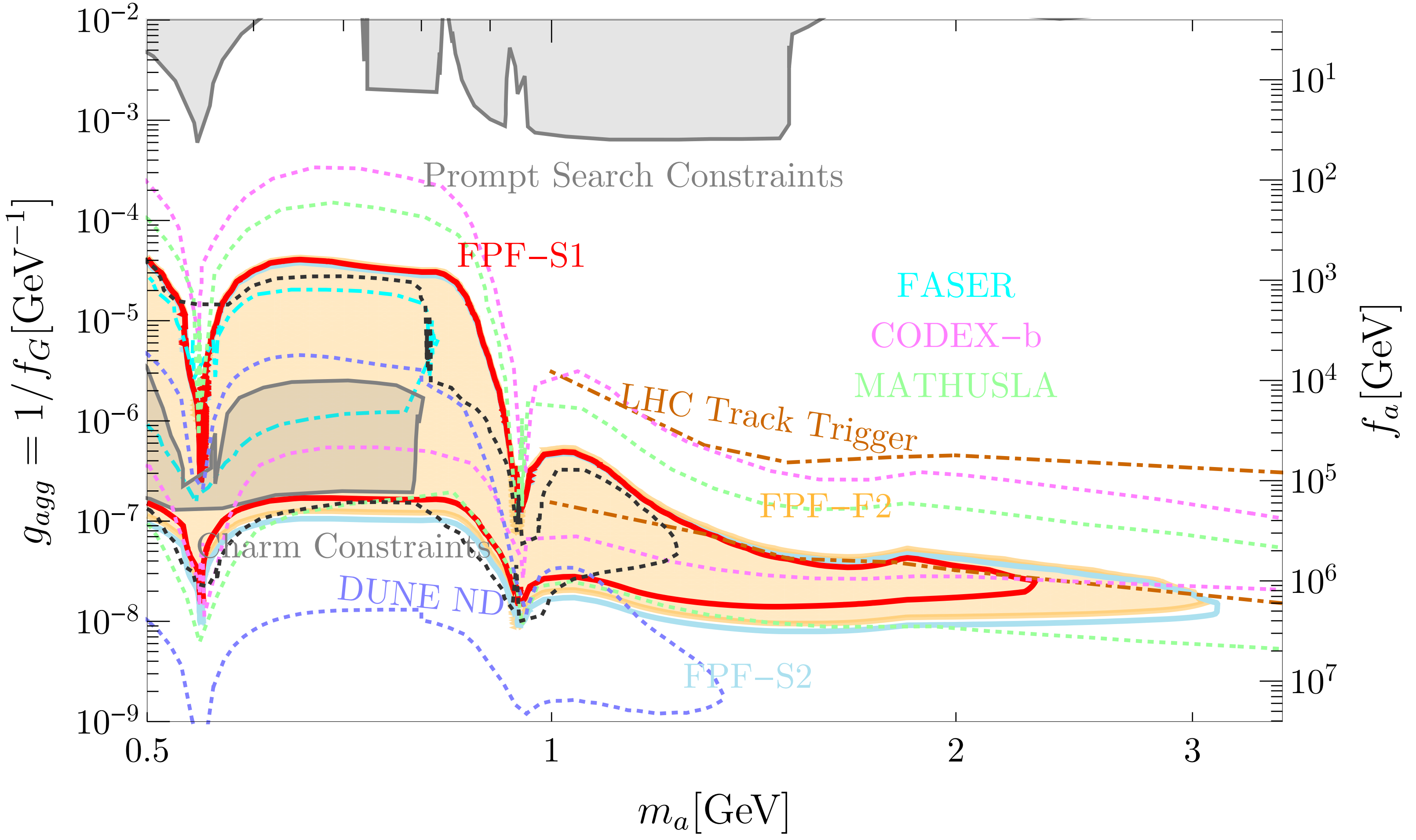
Scenario 1: Conservative



Scenario 2: Mixing effects



Scenario 1: $|C_p^0| \approx 0.47$ ignore the mixing Conservative!

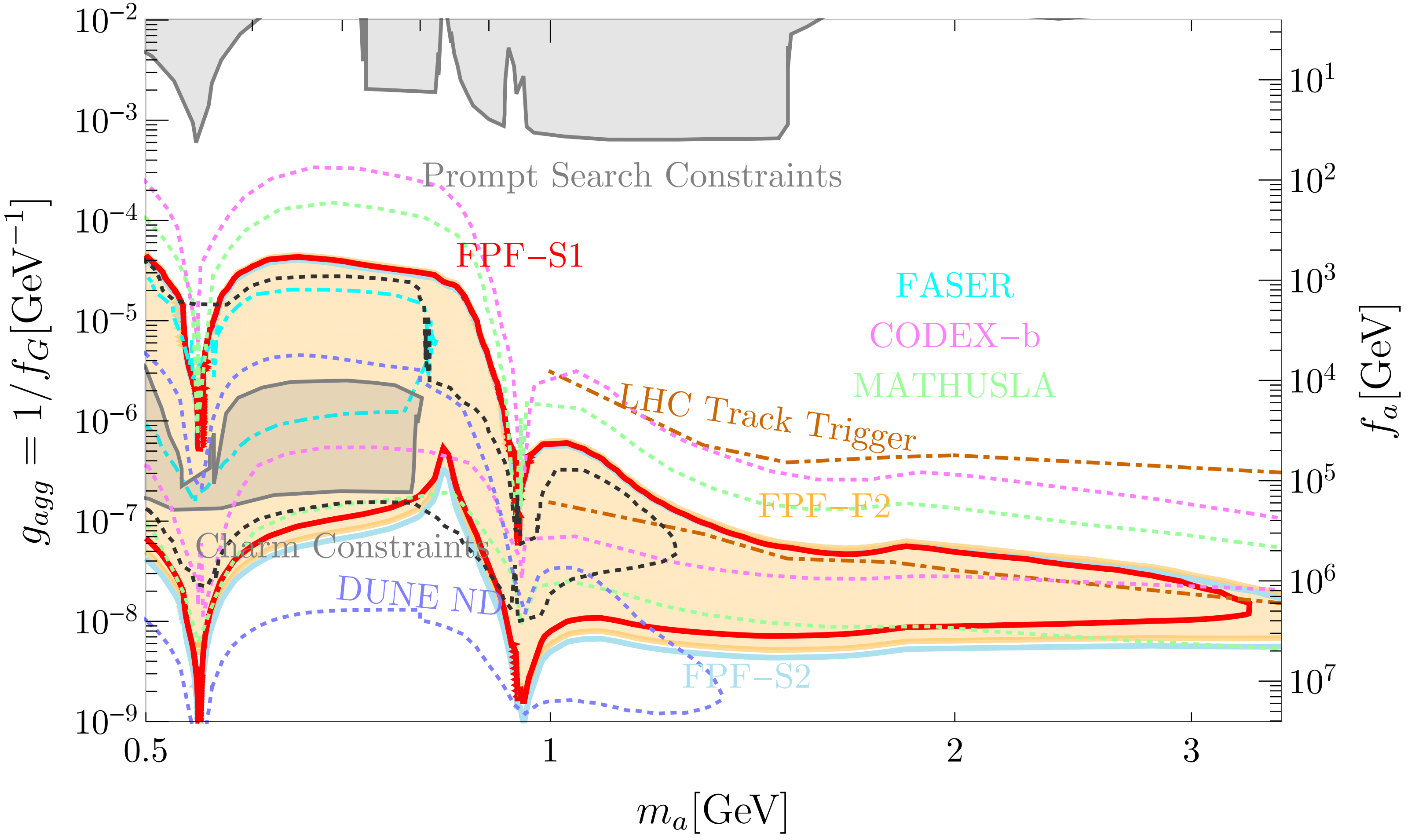


DUNE ND: 2011.05995
FASER: 1806.02348

LHC Track: 1911.12364
FASER2: 1811.12522

CODEX-b: 1911.00481
MATHUSLA: 1606.06298

Scenario 2: $g_{\pi^0 pp} = g_{\eta pp} = g_{\eta' pp}$ Approximately show the mixing effects.



Conclusion

The ALP production from proton bremsstrahlung process can enhance the previous FASER and FASER2 projected sensitivity and complementary for other experiments.

Thank you!