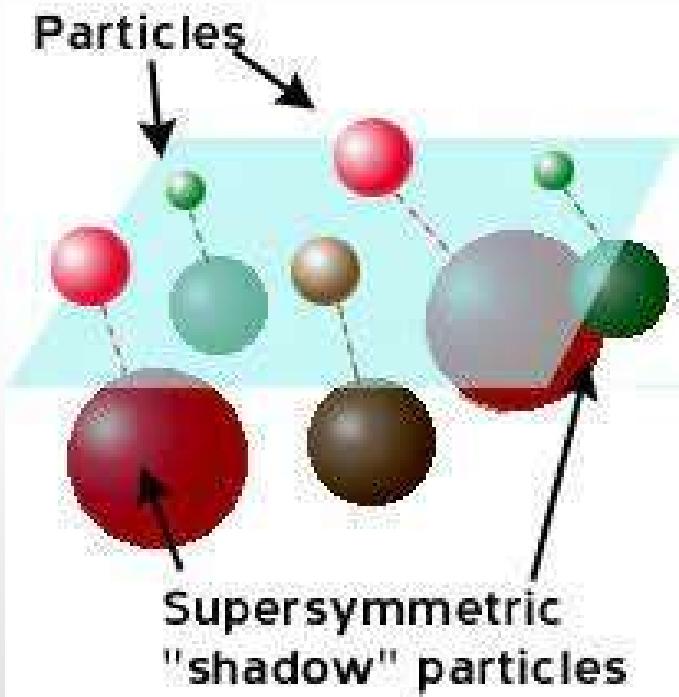


QUARKS-2020

SGOLDSTINO SEARCHES AT FASER

Kalashnikov Dmitry
Moscow Institute of Physics and Technology

Gorbunov Dmitry

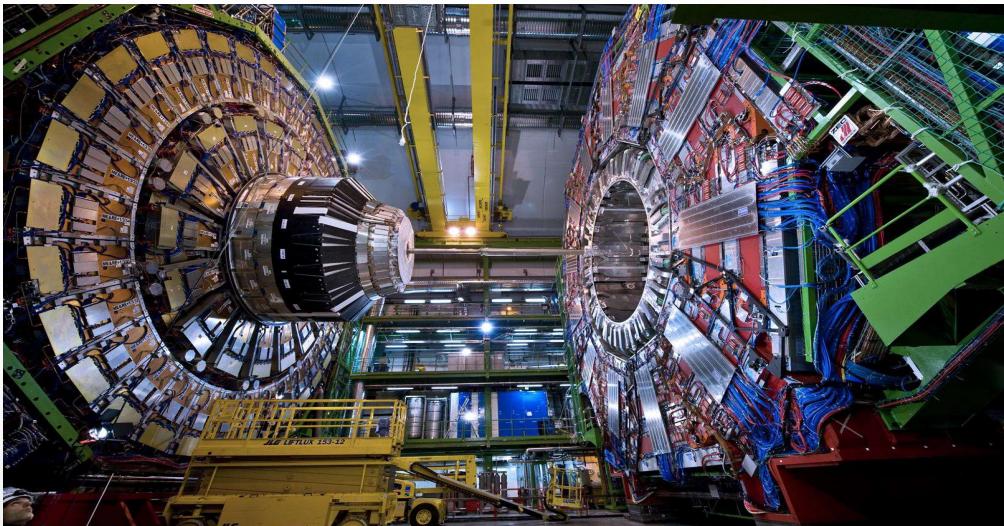


Supersymmetric extension of the Standard Model is a promising theory for new physics beyond SM

Supersymmetry spontaneously breaks and gives goldstino and its superpartner sgoldstino

Sgoldstino couples to SM particles and can be found in future experiments

Searches for new particles

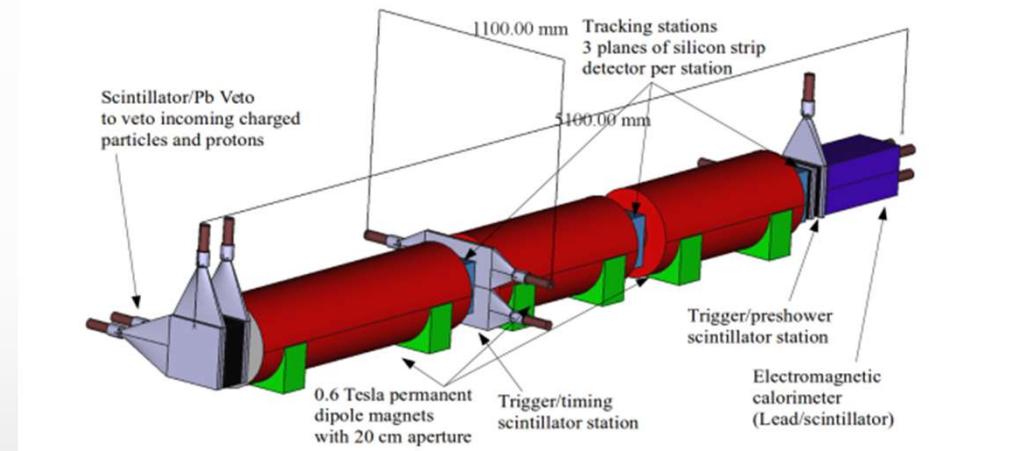


LHC ATLAS

LHC – the biggest science project in the world

LHC – confirmation of existing theories

LHC – searches for new theories



FASER detector layout

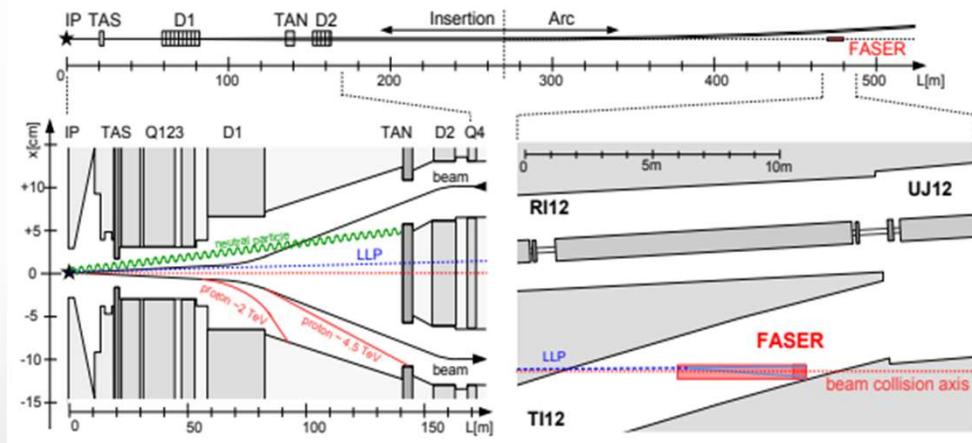
FASER – searches for light, weakly-interacting particles

FASER – far-forward detector

2 stages: FASER1 ($L = 150 \text{ fb}^{-1}$) and FASER2 ($L = 3000 \text{ fb}^{-1}$)

FASER

Sgoldstino model



Free parameters: $m_S, F, M_3, M_{\gamma\gamma}, A_Q, A_l, m_{F}^{LR}_{ij}$

$$100 \text{ GeV} < M_{\gamma\gamma}, A_Q, A_l < \sqrt{F}$$

$$3 \text{ TeV} < M_3 < \sqrt{F}$$

$$m_{F}^{LR}_{ij} < 100 \text{ GeV}$$

Sources: pp-scattering, Meson decay

Decay modes: $\gamma\gamma, l^+l^-$, dimeson decay

Sgoldstino model

$$\mathcal{S} = s + \sqrt{2}\theta\psi + \theta^2 F_s$$

$$\langle F_s \rangle \equiv F$$

$$s = \frac{1}{\sqrt{2}}(S + iP) \text{ - R-even}$$

$$\mathcal{L} = \frac{1}{F} J_{SUSY}^\mu \partial_\mu \psi$$

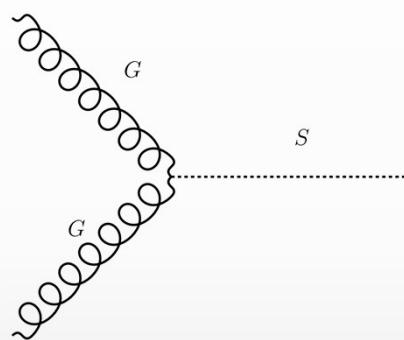
Current can be characterized by a mass parameter ΔM
 ΔM is a typical mass split within the supermultiplets

Mass of superpartner is
larger than mass of known
particles, therefore $\Delta M \approx$
 M_i , where i – particle
index.

$$\mathcal{L}_\gamma = \frac{M_{\gamma\gamma}}{2\sqrt{2}F} S F_{\mu\nu} F^{\mu\nu}$$

Sgoldstino sources

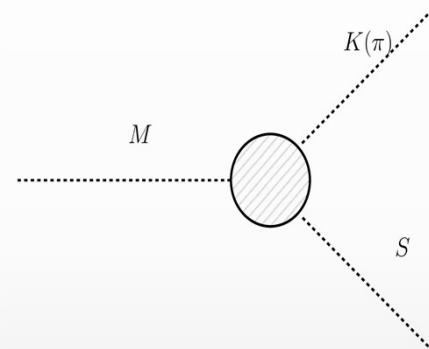
Gluon fission



$$\sigma \propto \frac{M_3^2}{F^2}$$

CompHEP \longrightarrow fit \longrightarrow $\frac{M_3^2}{F^2} \longrightarrow \sigma_{eff}$

Meson decay
 B, D, K_s, η



CRMC (EPOS-LHC) $\longrightarrow K_s, \eta$
LHCb $\longrightarrow B, D$
(arXiv:1710.04921; JHEP03(2016)159)

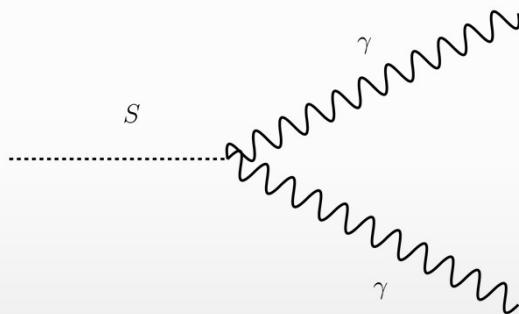
Flavor conserving Flavor violating

$$\Gamma \propto \left(\theta + \frac{A_Q}{F} \right)^2$$

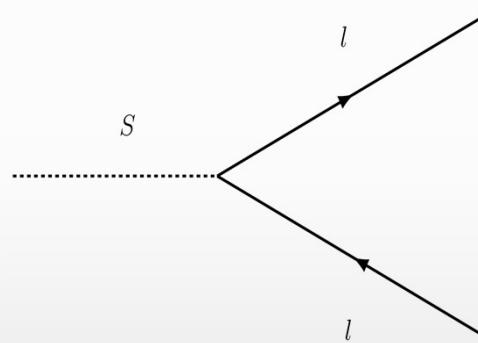
$$\Gamma \propto \frac{m_{F\ ij}^{LR}}{F^2}$$

Sgoldstino decays

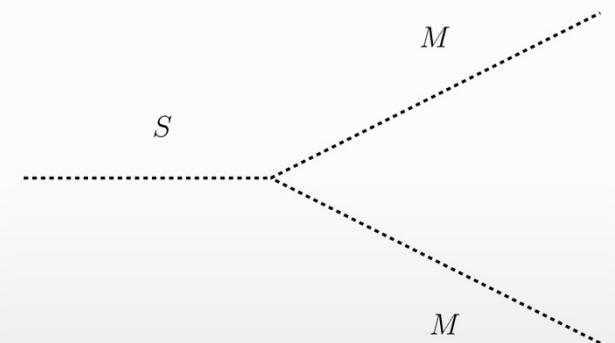
Photon



Lepton



Meson (π, K)

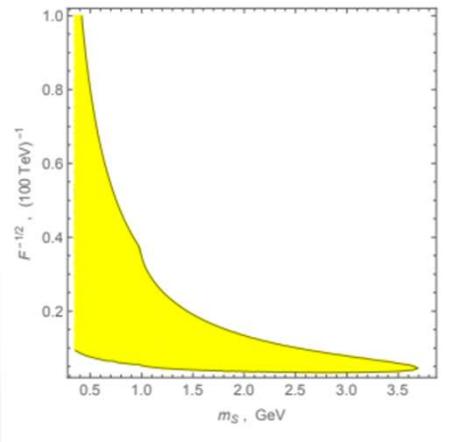


$$\Gamma \propto \frac{{M_{\gamma\gamma}}^2}{F^2}$$

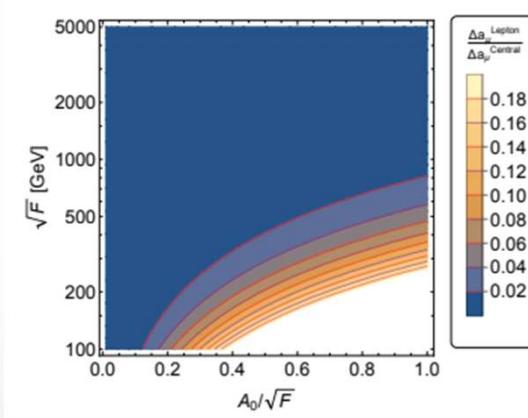
$$\Gamma \propto \frac{{A_l}^2}{F^2}$$

$$\Gamma \propto \frac{{M_3}^2}{F^2}, \frac{{A_Q}^2}{F^2}$$

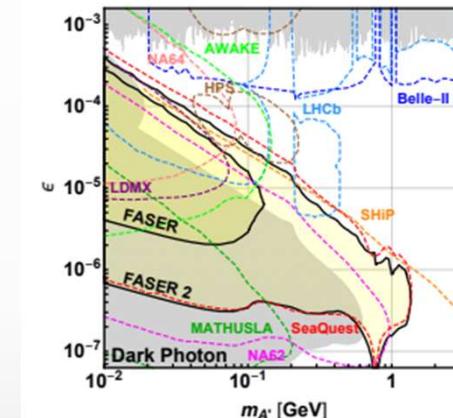
Other studies



K. O. Astapov, D. S. Gorbunov. «Decaying light particles in the SHiP experiment. III. Signal rate estimates for scalar and pseudoscalar sgoldstinos». arXiv:1511.05403



Xuewen Liu, Ying Li, Tianjun Li, Bin Zhu. «The Light Sgoldstino Phenomenology: Explanations for the Muon $(g - 2)$ Deviation and KOTO Anomaly». arXiv:2006.08869



FASER collaboration.
«FASER's Physics Reach for Long-Lived Particles». arXiv:1811.12522

Scope:

determine soft-parameter space
that will be probed at FASER

With $M_3 = M_{\gamma\gamma} = A_l = A_Q$: $\Gamma_{\pi\pi} \gg \Gamma_{\gamma\gamma}, \Gamma_{ll} \Rightarrow$
 \Rightarrow it is convenient to consider 2 cases with
sgoldstino mass (m_S)



Soft parameters space (FASER2) Photon

$$m_S < 2m_\pi$$

$$3 \text{ TeV} < \sqrt{F} < 7 \cdot 10^3 \text{ TeV}$$

$$100 \text{ GeV} < M_{\gamma\gamma} < \sqrt{F}$$

$$100 \text{ GeV} < A_Q < \sqrt{F}$$

$$3 \text{ TeV} < M_3 < \sqrt{F}$$

$$m_{F_{ij}}^{LR} < 100 \text{ GeV}$$

$$2m_\pi < m_S < 4 \text{ GeV}$$

$$150 \text{ TeV} < \sqrt{F} < 7 \cdot 10^3 \text{ TeV}$$

$$150 \text{ TeV} < M_{\gamma\gamma} < \sqrt{F}$$

$$100 \text{ GeV} < A_Q < 10 M_{\gamma\gamma}$$

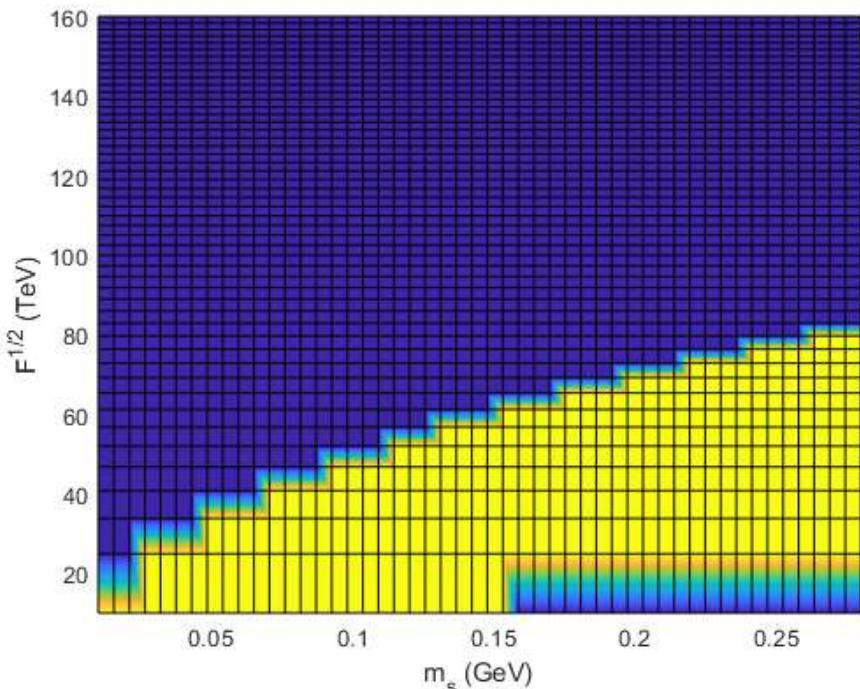
$$3 \text{ TeV} < M_3 < 0.02 M_{\gamma\gamma}$$

$$m_{F_{ij}}^{LR} < 100 \text{ GeV}$$

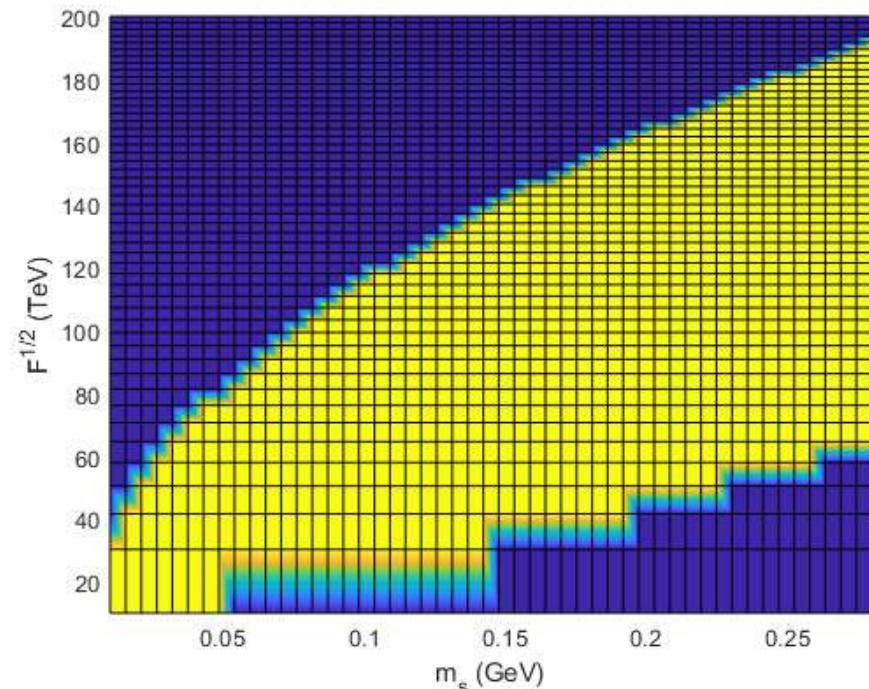
Soft parameters space (FASER2)

Source: Gluon fission

Decay: Photon



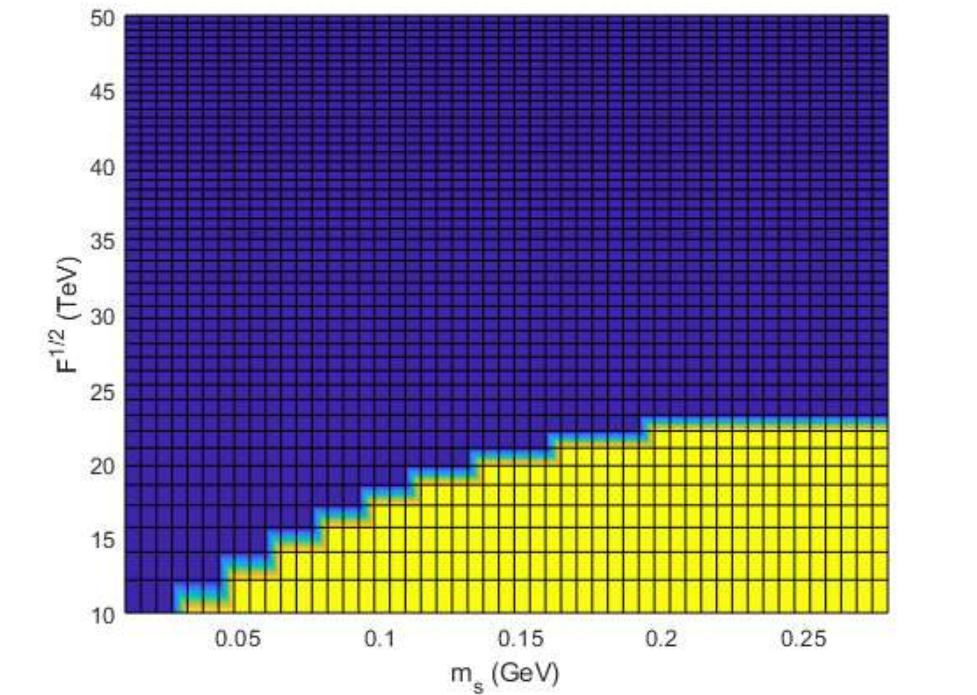
$$M_{\gamma\gamma} = 1 \text{ TeV}; M_3 = 3 \text{ TeV}$$



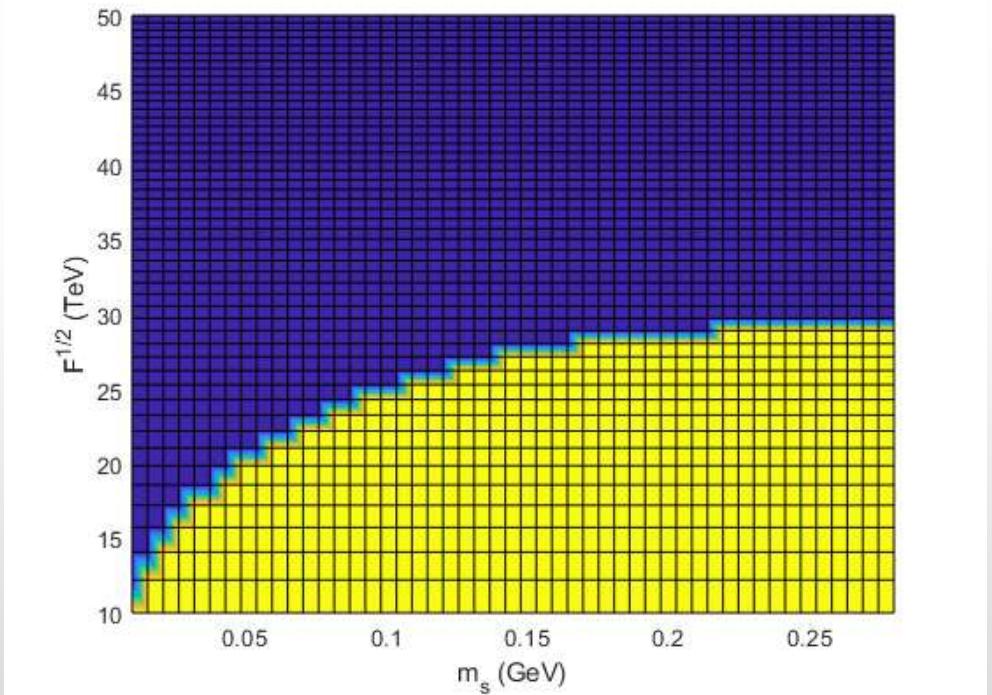
$$M_{\gamma\gamma} = 10 \text{ TeV}; M_3 = 10 \text{ TeV}$$

Soft parameters space (FASER2)

Source: Flavor conserving meson decay (η) Decay: Photon



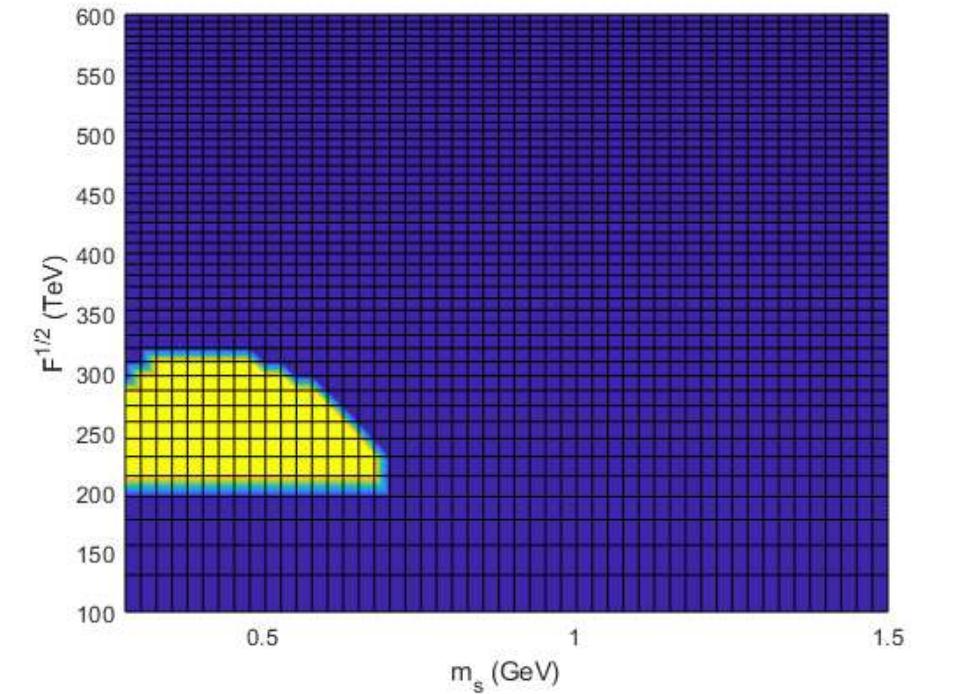
$$A_Q = 100 \text{ GeV}; M_{\gamma\gamma} = 1 \text{ TeV};$$



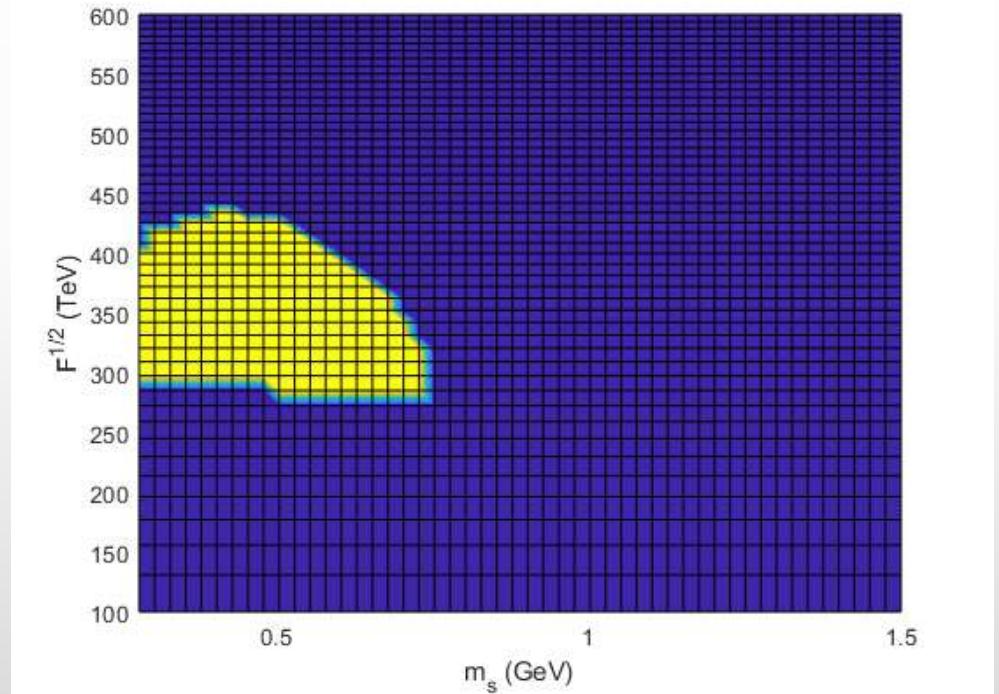
$$A_Q = 100 \text{ GeV}; M_{\gamma\gamma} = 1 \text{ TeV};$$

Soft parameters space (FASER2)

Source: Flavor conserving meson decay (B) Decay: Photon



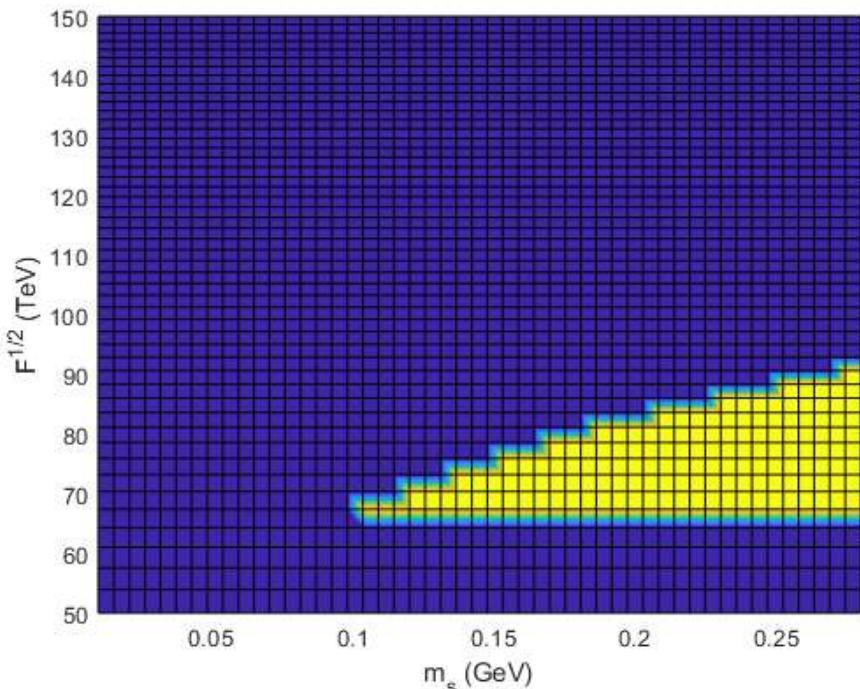
$$A_Q = 10 \text{ TeV}; M_{\gamma\gamma} = 50 \text{ TeV};$$



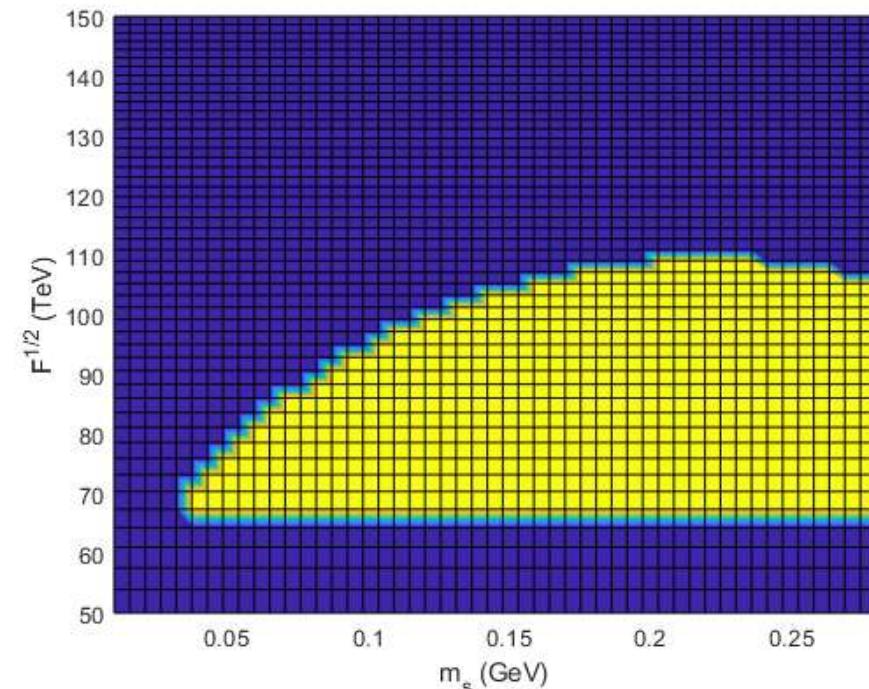
$$A_Q = 100 \text{ TeV}; M_{\gamma\gamma} = 100 \text{ TeV};$$

Soft parameters space (FASER2)

Source: Flavor violating meson decay (D) Decay: Photon



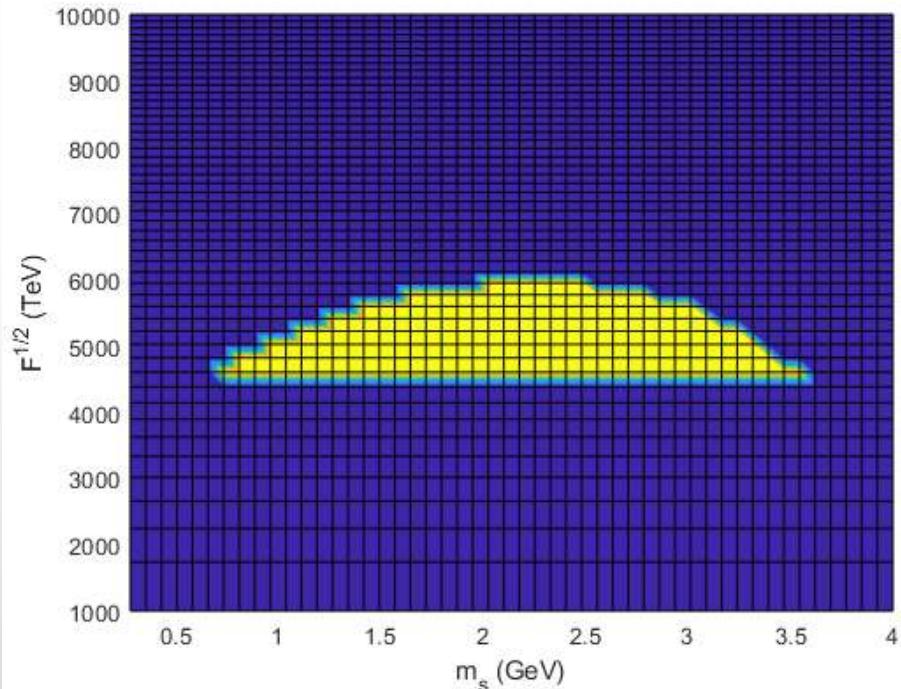
$$M_{\gamma\gamma} = 1 \text{ TeV}; m_F^{LR} = 10 \text{ GeV}$$



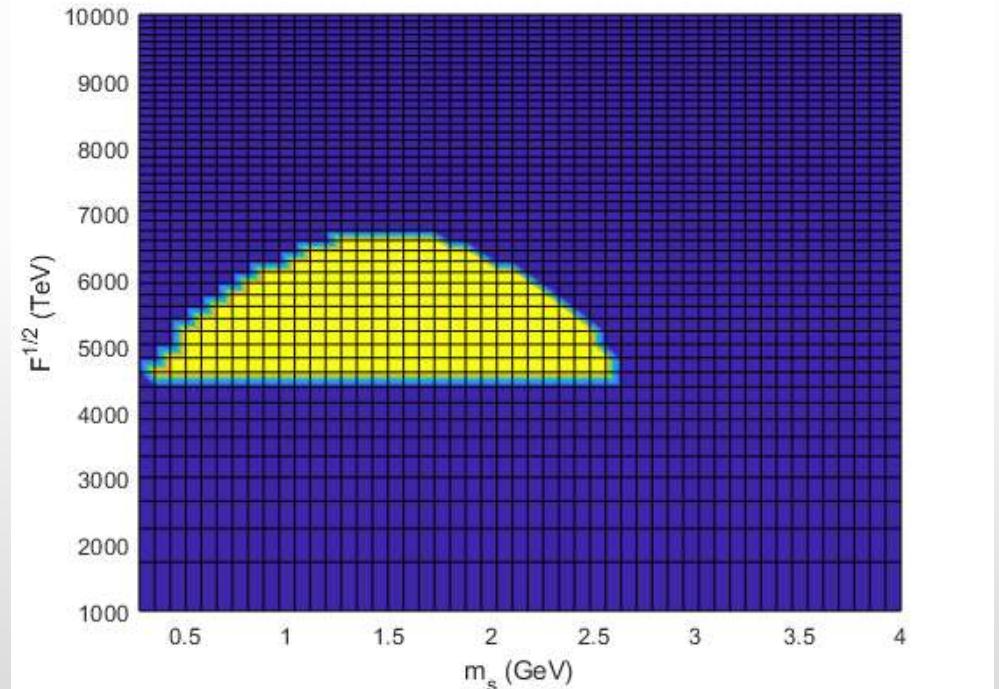
$$M_{\gamma\gamma} = 10 \text{ TeV}; m_F^{LR} = 10 \text{ GeV}$$

Soft parameters space (FASER2)

Source: Flavor violating meson decay (B) Decay: Photon



$$M_{\gamma\gamma} = 500 \text{ TeV}; m_F^{LR} = 100 \text{ GeV}$$



$$M_{\gamma\gamma} = 2000 \text{ TeV}; m_F^{LR} = 100 \text{ GeV}$$

Soft parameter space (FASER1) Photon

$$m_S < 2m_\pi$$

$$3 \text{ TeV} < \sqrt{F} < 400 \text{ TeV}$$

$$100 \text{ GeV} < M_{\gamma\gamma} < \sqrt{F}$$

$$100 \text{ GeV} < A_Q < \sqrt{F}$$

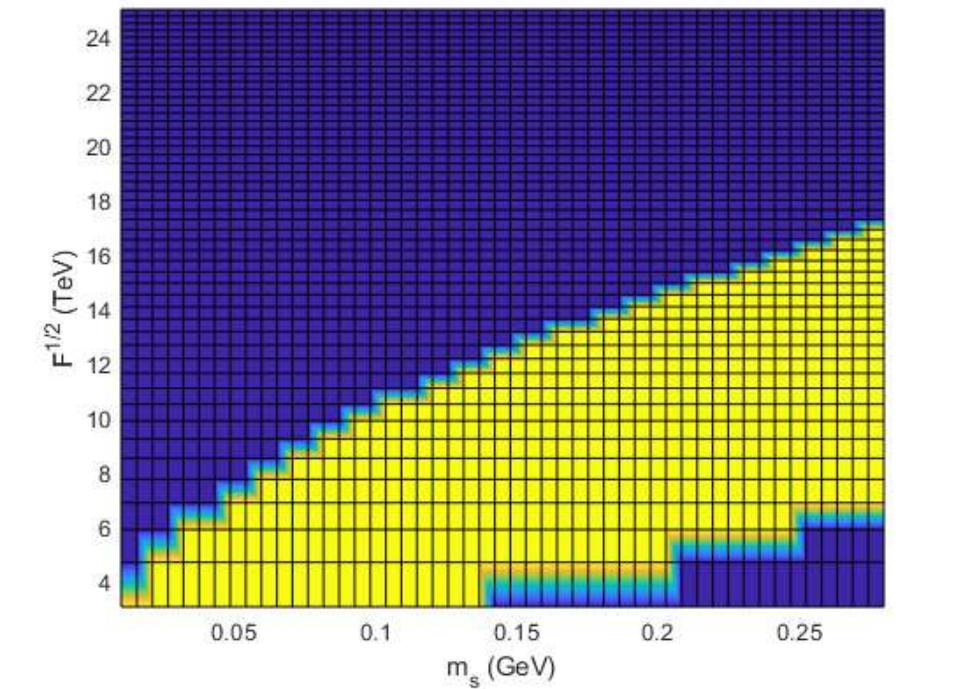
$$3 \text{ TeV} < M_3 < \sqrt{F}$$

$$m_F^{LR}{}_{ij} < 1 \text{ GeV}$$

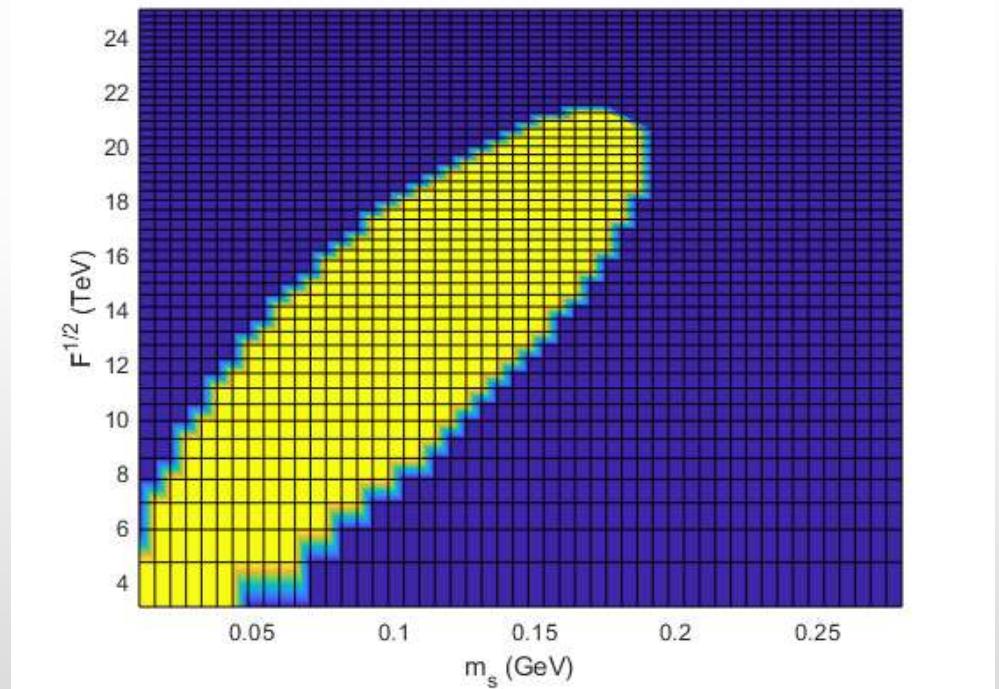
Soft parameters space (FASER1)

Source: Gluon fission

Decay: Photon



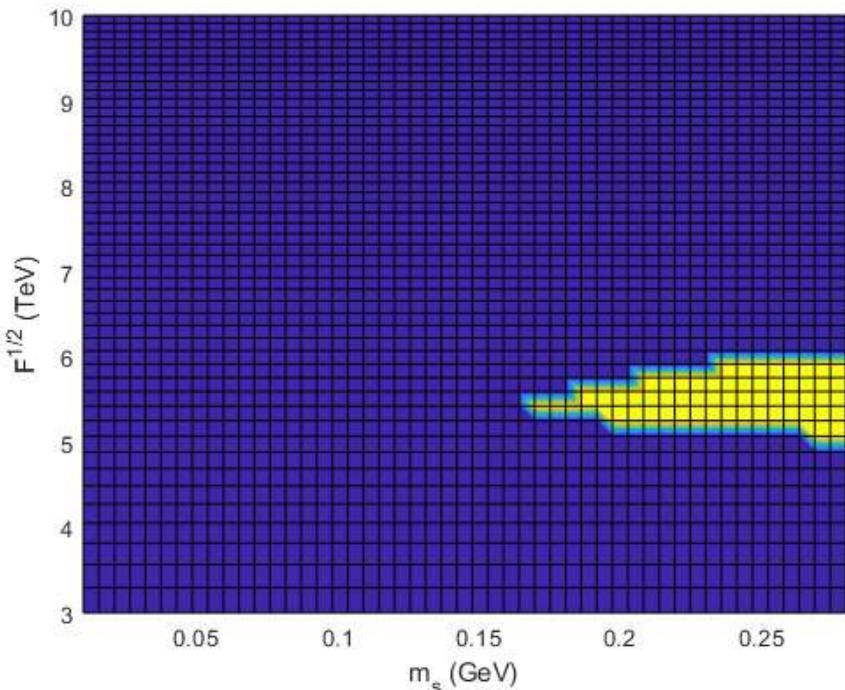
$M_{\gamma\gamma} = 100 \text{ GeV}; M_3 = 3 \text{ TeV}$



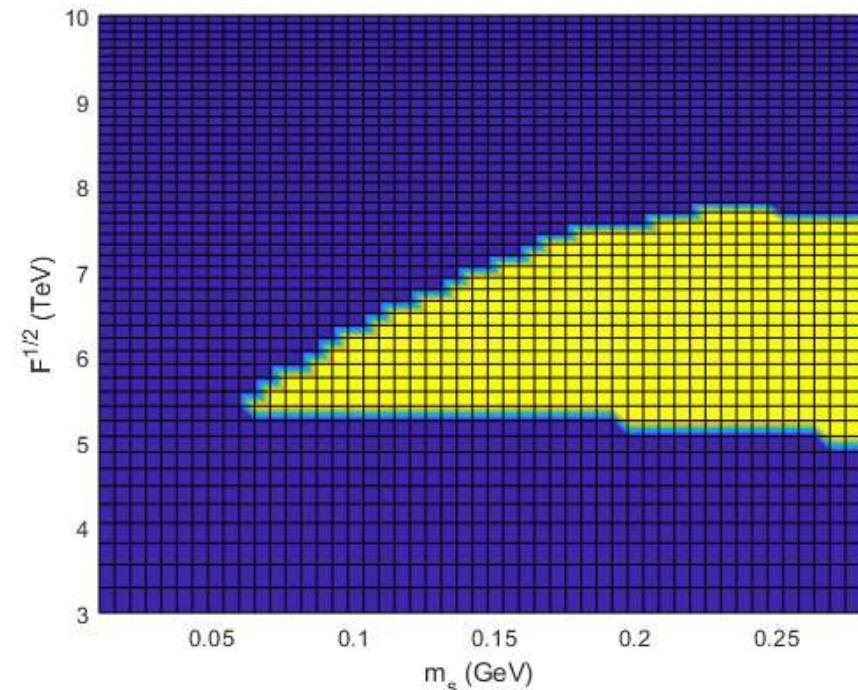
$M_{\gamma\gamma} = 1 \text{ TeV}; M_3 = 3 \text{ TeV}$

Soft parameters space (FASER1)

Source: Flavor conserving meson decay (η) Decay: Photon



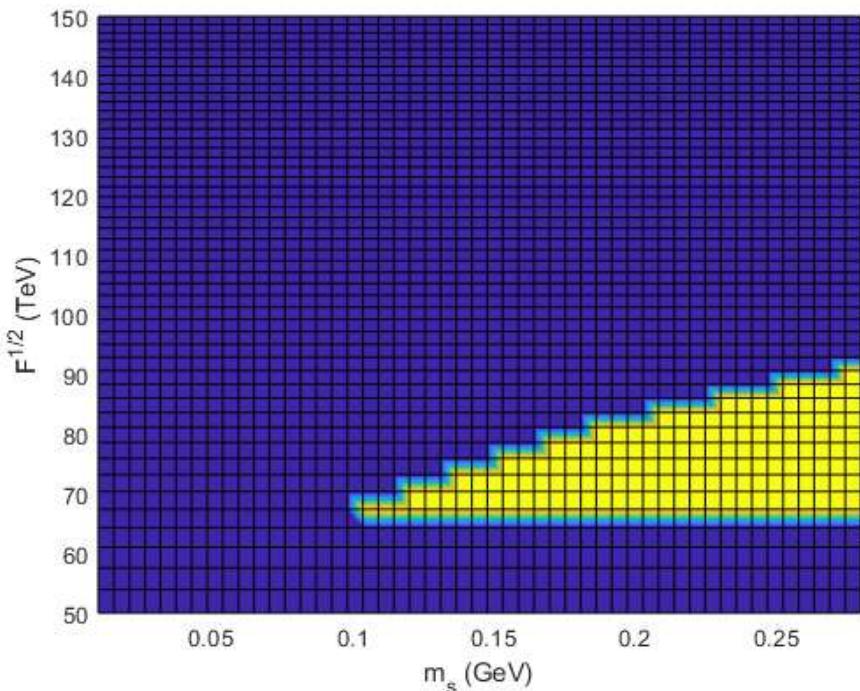
$$A_Q = 100 \text{ GeV}; M_{\gamma\gamma} = 100 \text{ GeV};$$



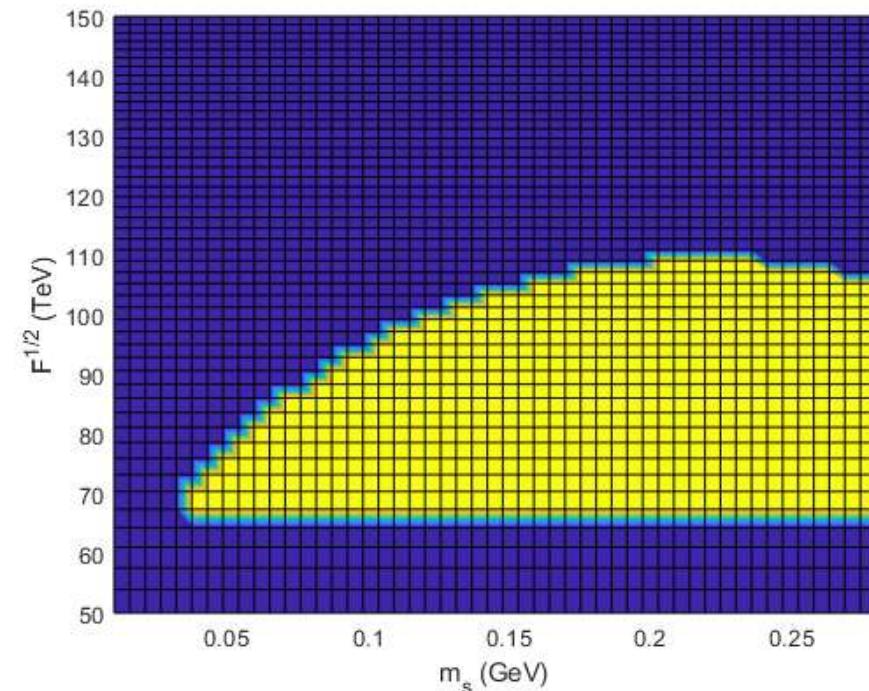
$$A_Q = 100 \text{ GeV}; M_{\gamma\gamma} = 1 \text{ TeV};$$

Soft parameters space (FASER1)

Source: Flavor violating meson decay (η) Decay: Photon



$$M_{\gamma\gamma} = 1 \text{ TeV}; m_F^{LR} = 10 \text{ GeV}$$



$$M_{\gamma\gamma} = 10 \text{ TeV}; m_F^{LR} = 10 \text{ GeV}$$

Soft parameters space (FASER1)

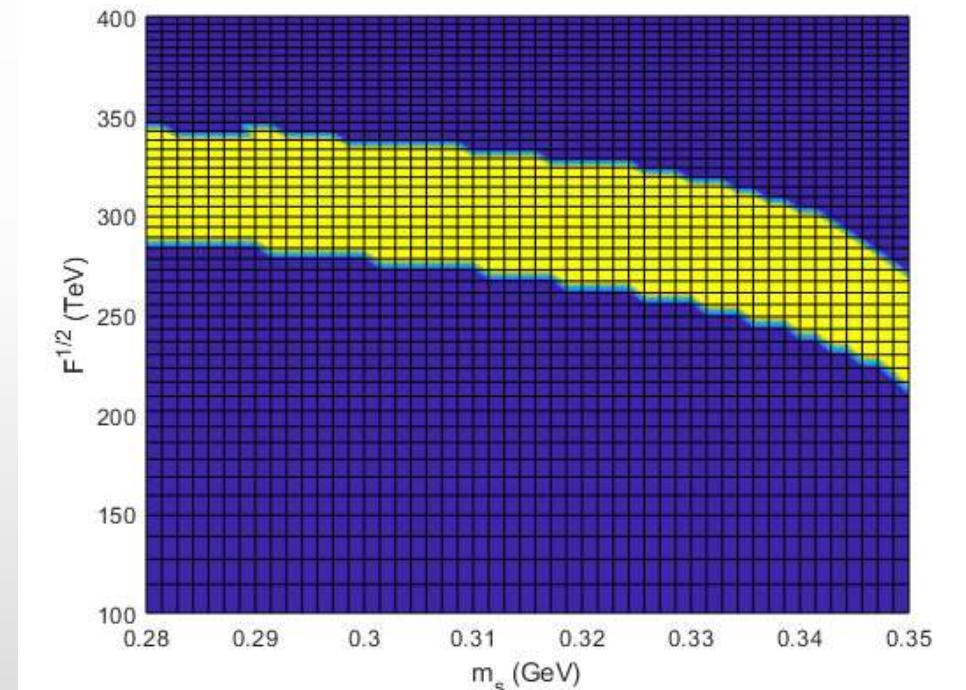
Source: Flavor violating meson decay (η) Decay: Photon

$$2m_\pi < m_s < 0.35 \text{ GeV}$$

$$20 \text{ TeV} < \sqrt{F} < 350 \text{ TeV}$$

$$50 \text{ TeV} < M_{\gamma\gamma} < \sqrt{F}$$

$$10 \text{ GeV} < m_F^{LR}_{ij} < 100 \text{ GeV}$$



$$M_{\gamma\gamma} = \sqrt{F}; \quad m_F^{LR} = 100 \text{ GeV}$$

Soft parameter space (FASER2) Lepton

$$m_S < 2m_\pi$$

$$3 \text{ TeV} < \sqrt{F} < 10^3 \text{ TeV}$$

$$2 \text{ TeV} < A_l < \sqrt{F}$$

$$100 \text{ GeV} < A_Q < \sqrt{F}$$

$$3 \text{ TeV} < M_3 < \sqrt{F}$$

$$m_{F_{ij}}^{LR} < 10 \text{ GeV}$$

Soft parameters space (FASER2)

Source: Gluon fission Decay: Lepton (e^+e^-)

$$m_s < 50 \text{ MeV}$$

$$10 \text{ TeV} < \sqrt{F} < 80 \text{ TeV}$$

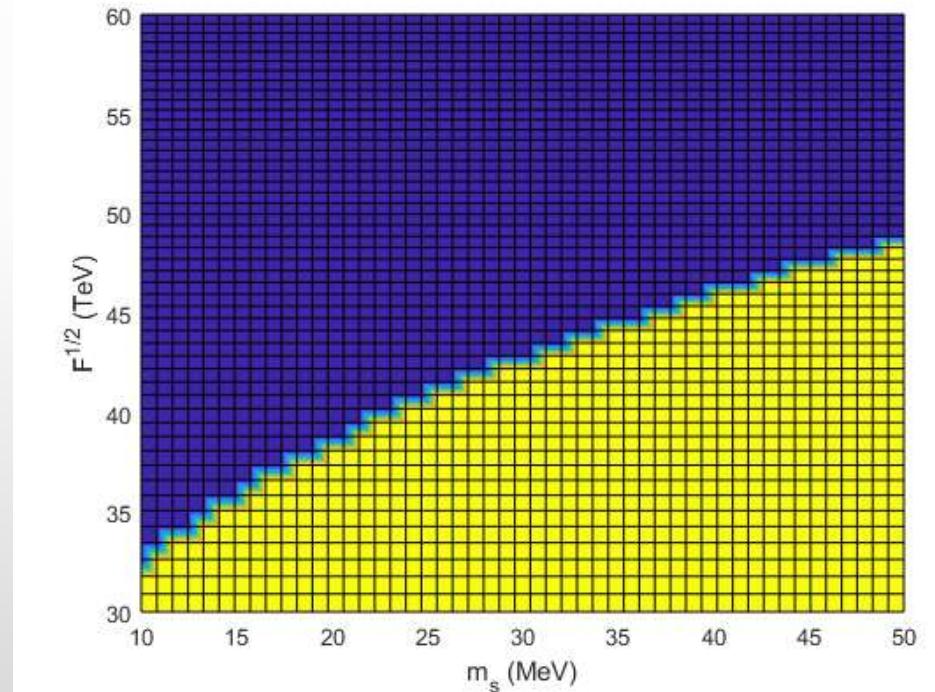
$$10 \text{ TeV} < A_l < \sqrt{F}$$

$$100 \text{ GeV} < M_{\gamma\gamma} < 0.02A_l$$

$$3 \text{ TeV} < M_3 < \sqrt{F}$$

$$50 \text{ MeV} < m_s < 2m_\mu$$

$$50M_{\gamma\gamma} < A_l < \sqrt{F}$$

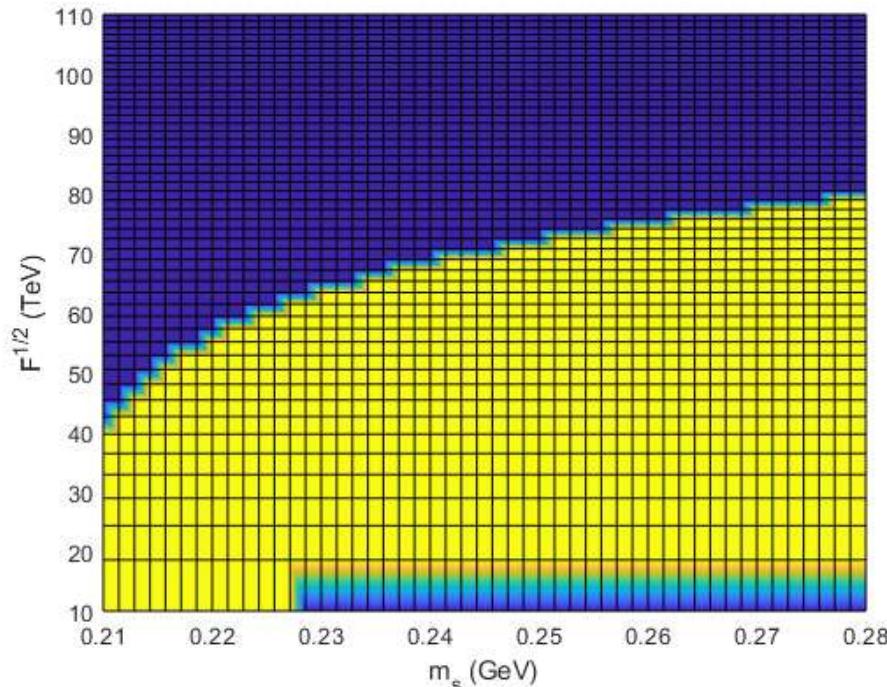


$$A_l = 30 \text{ TeV}; M_3 = 30 \text{ TeV};$$

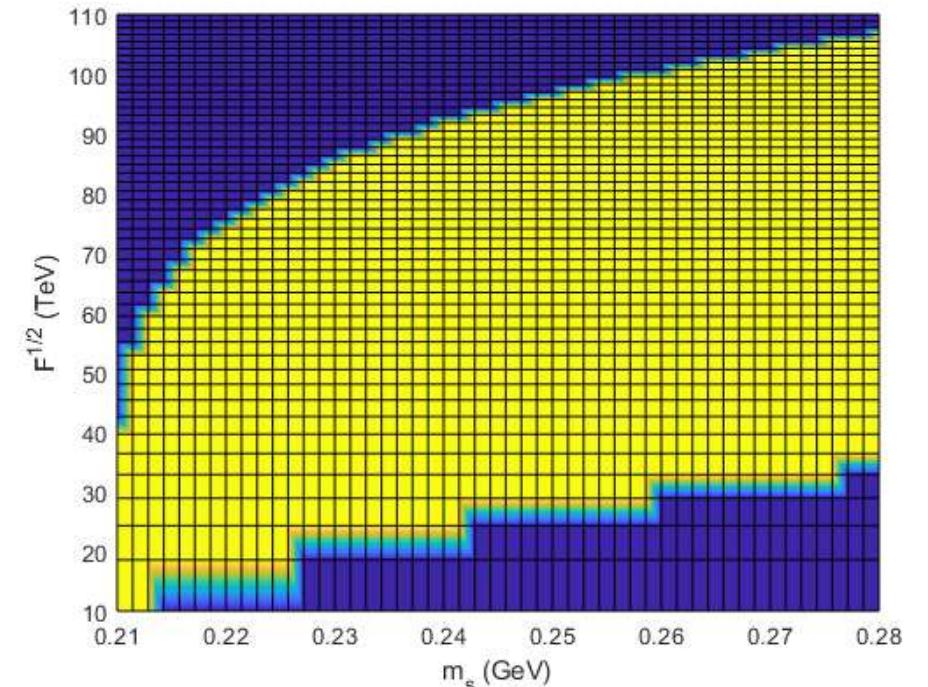
Soft parameters space (FASER2)

Source: Gluon fission

Decay: Lepton



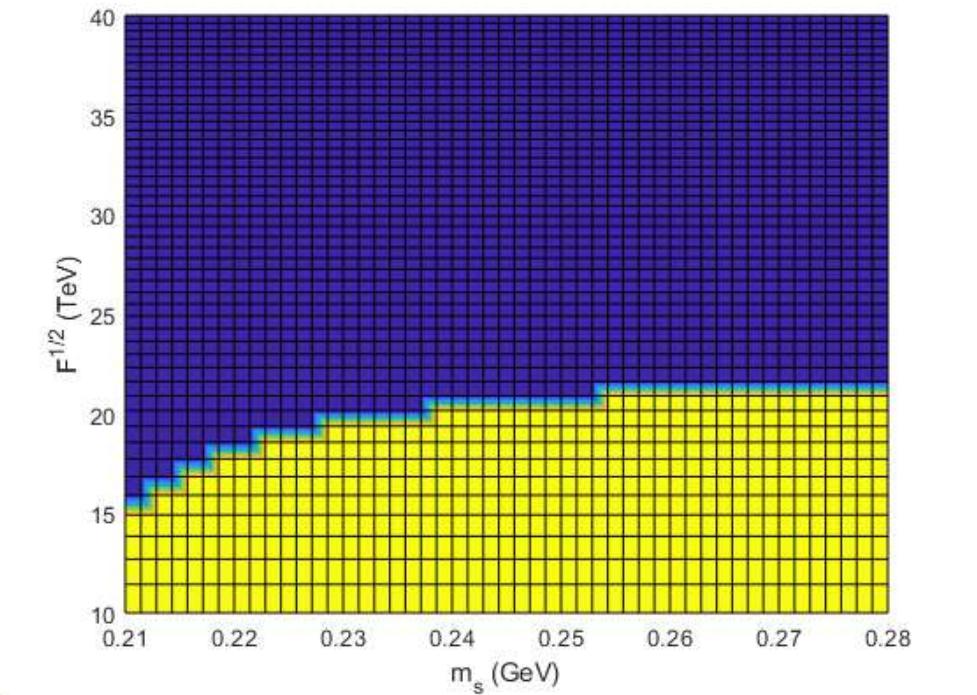
$$A_l = 3 \text{ TeV}; M_3 = 3 \text{ TeV};$$



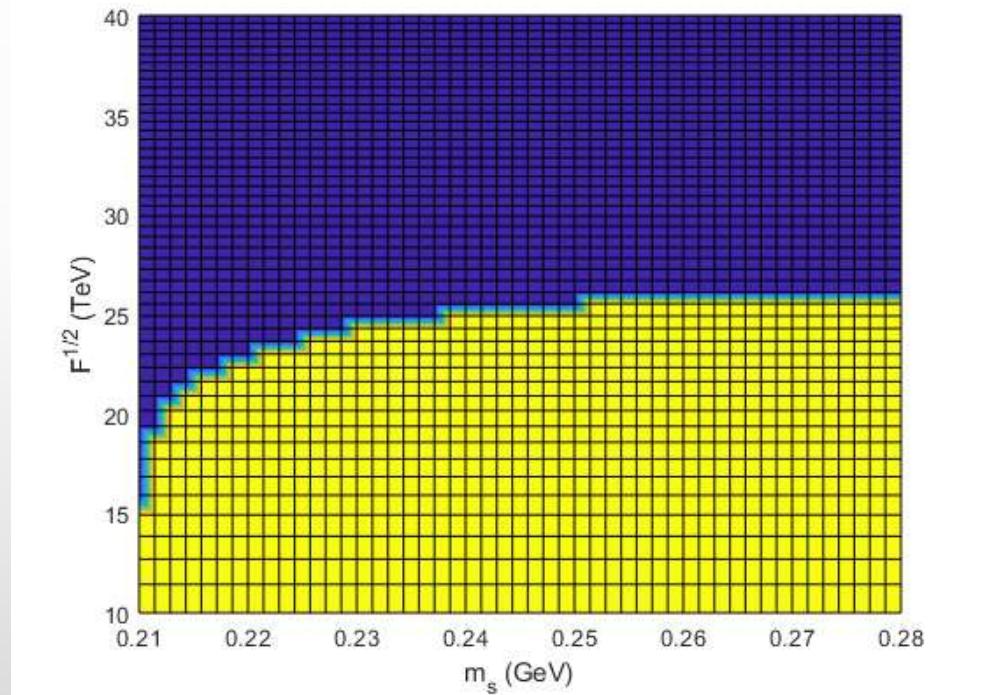
$$A_l = 10 \text{ TeV}; M_3 = 3 \text{ TeV};$$

Soft parameters space (FASER2)

Source: Flavor conserving meson decay (η) Decay: Lepton



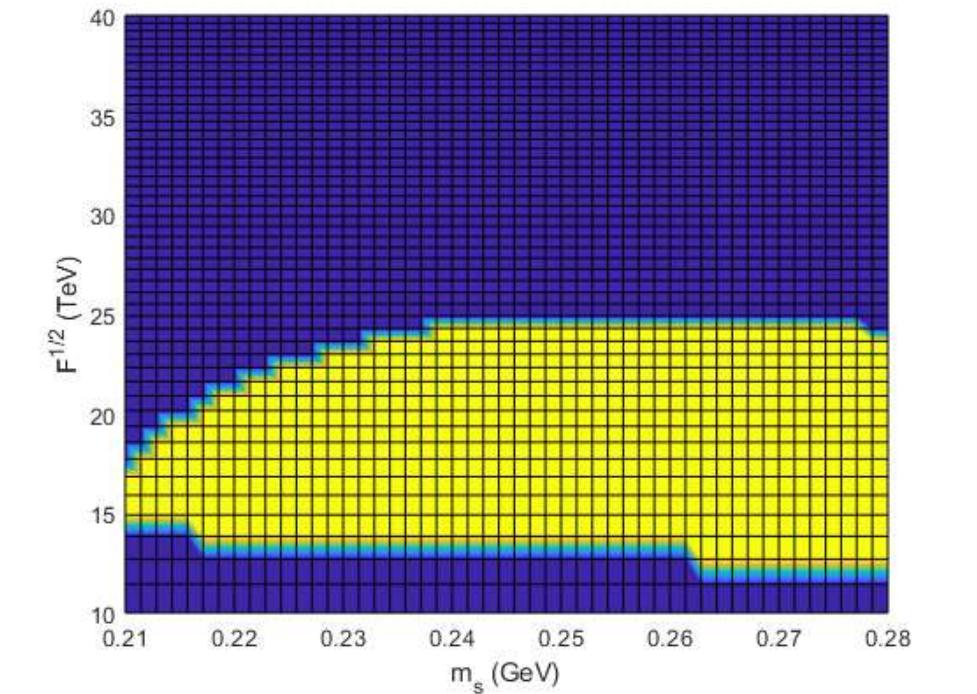
$A_Q = 100 \text{ GeV}; A_l = 2 \text{ TeV};$



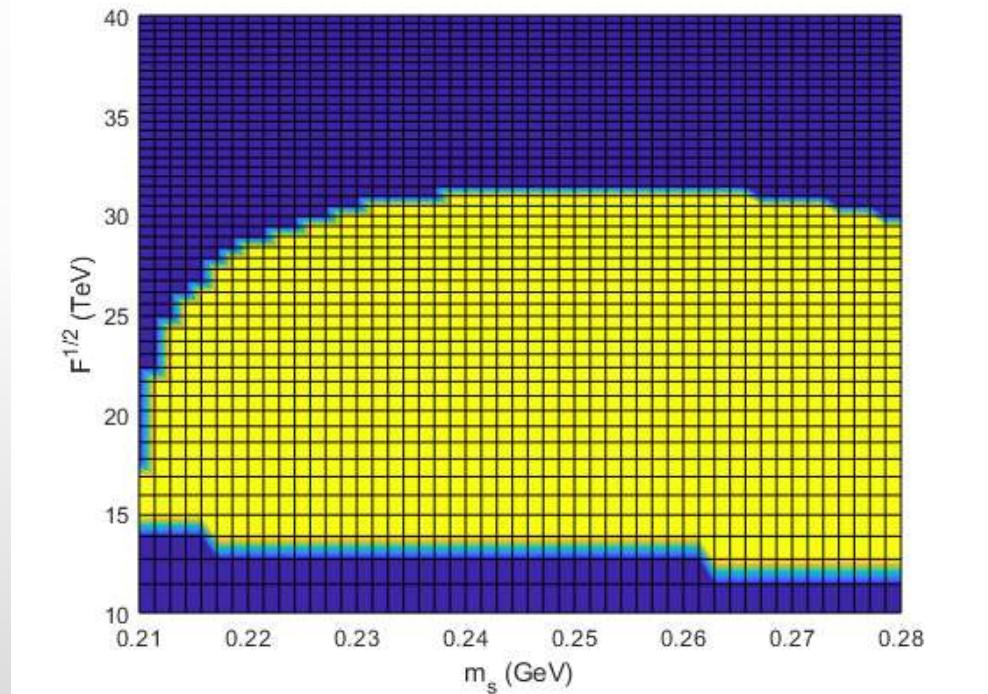
$A_Q = 100 \text{ GeV}; A_l = 10 \text{ TeV};$

Soft parameters space (FASER2)

Source: Flavor violating meson decay (K) Decay: Lepton



$$A_l = 2 \text{ TeV}; m_F^{LR} = 0.1 \text{ GeV}$$



$$A_l = 10 \text{ TeV}; m_F^{LR} = 0.1 \text{ GeV}$$

Soft parameters space (FASER2)

Source: Flavor violating meson decay (B) Decay: Lepton

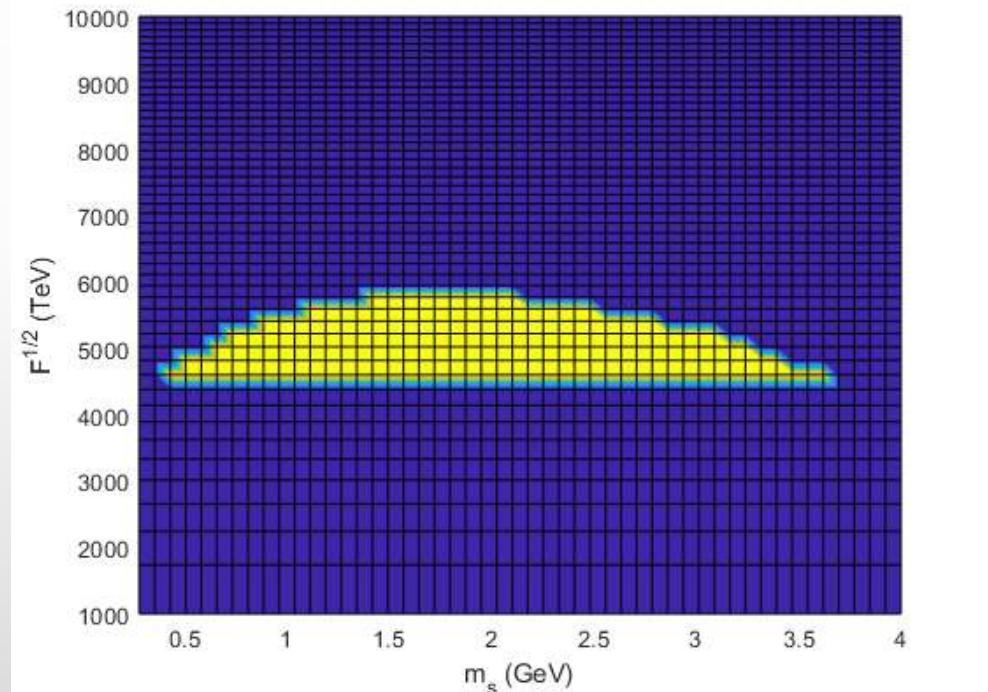
$$2m_\pi < m_S < 4 \text{ GeV}$$

$$4 \cdot 10^3 \text{ TeV} < \sqrt{F} < 6 \cdot 10^3 \text{ TeV}$$

$$2000 \text{ TeV} < A_l < \sqrt{F}$$

$$3 \text{ TeV} < M_3 < 0.002 A_l$$

$$m_F^{LR}{}_{ij} \approx 100 \text{ GeV}$$



$$A_l = \sqrt{F}; \quad m_F^{LR} = 100 \text{ GeV}$$

Soft parameter space (FASER1) Lepton

$$m_S < 2m_\pi$$

$$3 \text{ TeV} < \sqrt{F} < 10^2 \text{ TeV}$$

$$2 \text{ TeV} < A_l < \sqrt{F}$$

$$3 \text{ TeV} < M_3 < \sqrt{F}$$

$$m_{F_{ij}}^{LR} < 10 \text{ GeV}$$

Soft parameters space (FASER1)

Source: Gluon fission Decay: Lepton (e^+e^-)

$$m_s < 50 \text{ MeV}$$

$$10 \text{ TeV} < \sqrt{F} < 12 \text{ TeV}$$

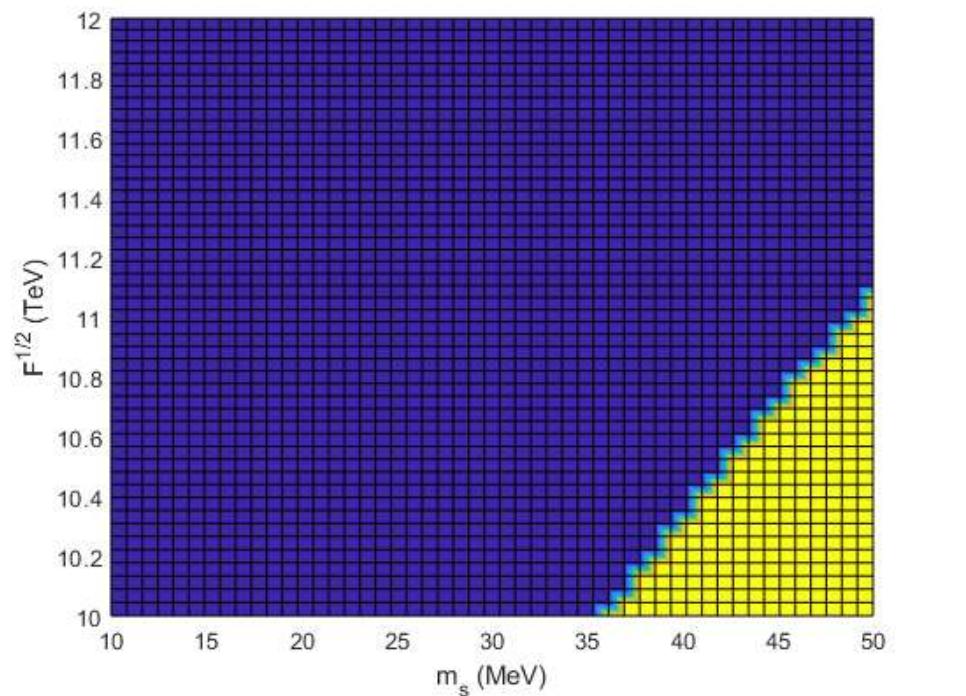
$$10 \text{ TeV} < A_l < \sqrt{F}$$

$$100 \text{ GeV} < M_{\gamma\gamma} < 0.02A_l$$

$$3 \text{ TeV} < M_3 < \sqrt{F}$$

$$50 \text{ MeV} < m_s < 2m_\mu$$

$$50M_{\gamma\gamma} < A_l < \sqrt{F}$$

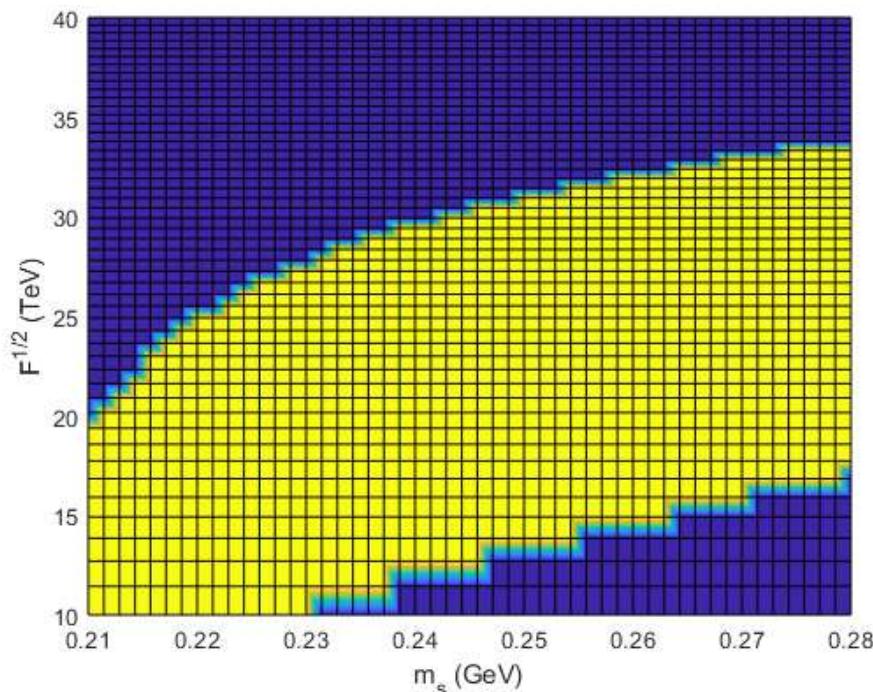


$$A_l = 5 \text{ TeV}; M_3 = 5 \text{ TeV};$$

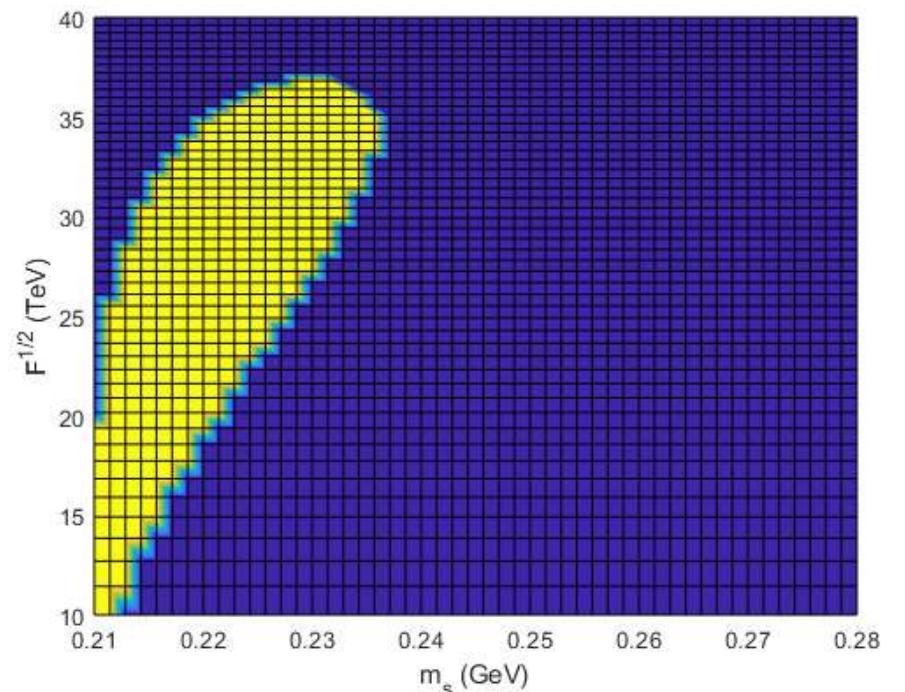
Soft parameters space (FASER1)

Source: Gluon fission

Decay: Lepton



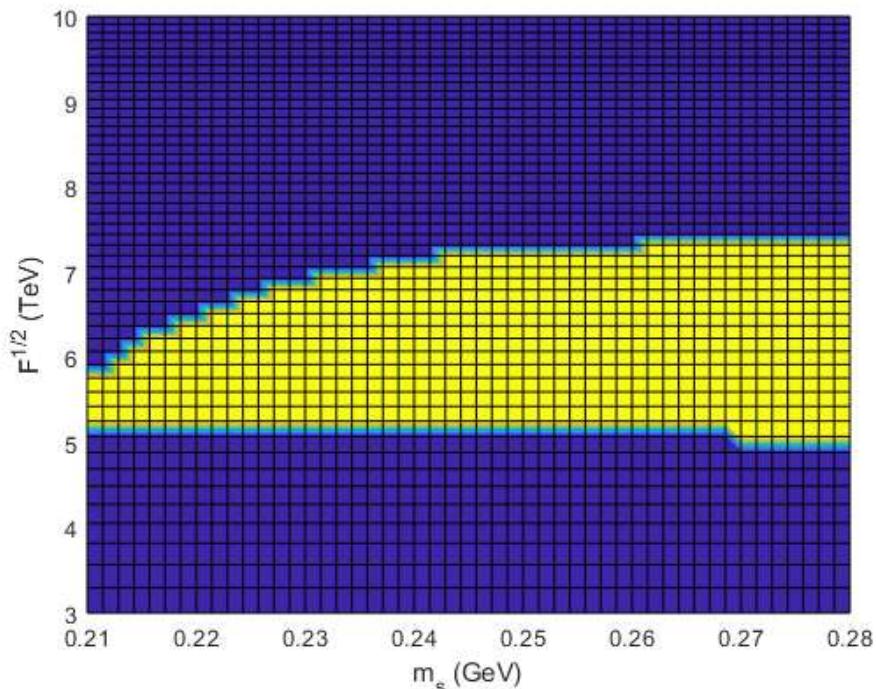
$$A_l = 2 \text{ TeV}; M_3 = 10 \text{ TeV}$$



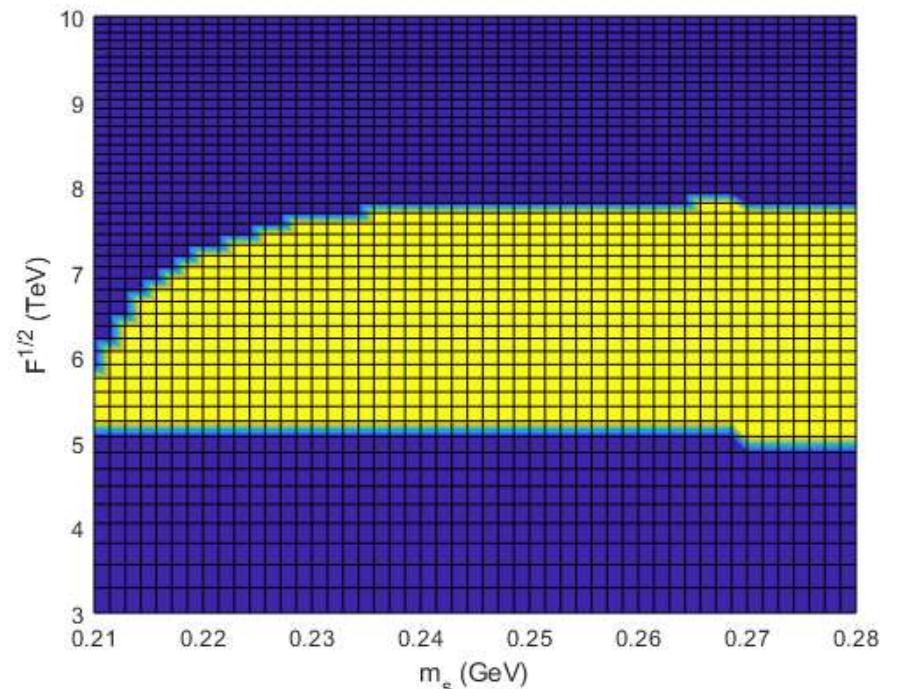
$$A_l = 10 \text{ TeV}; M_3 = 10 \text{ TeV}$$

Soft parameters space (FASER1)

Source: Flavor conserving meson decay (η) Decay: Lepton



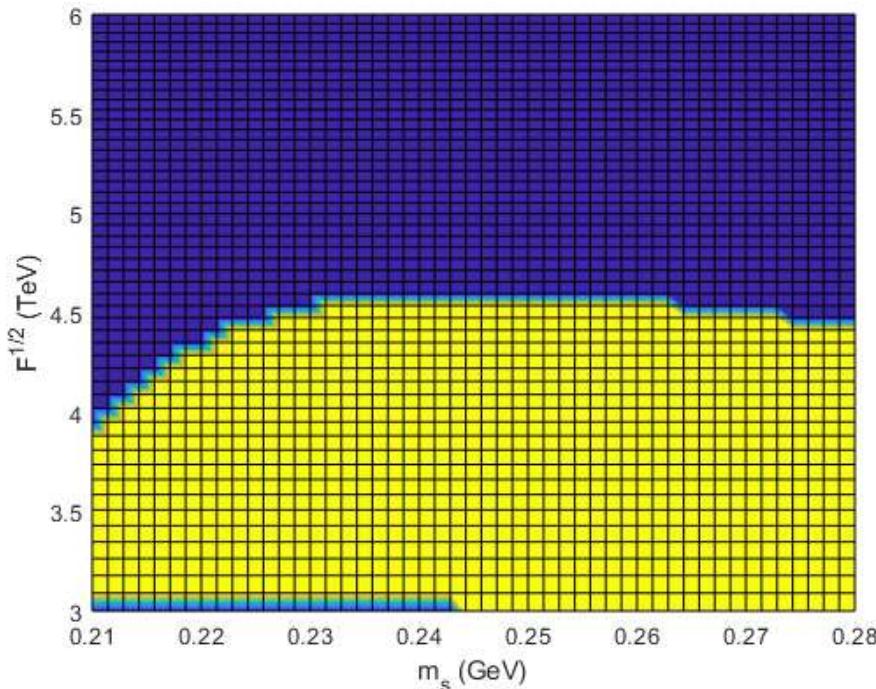
$$A_l = 2 \text{ TeV}$$



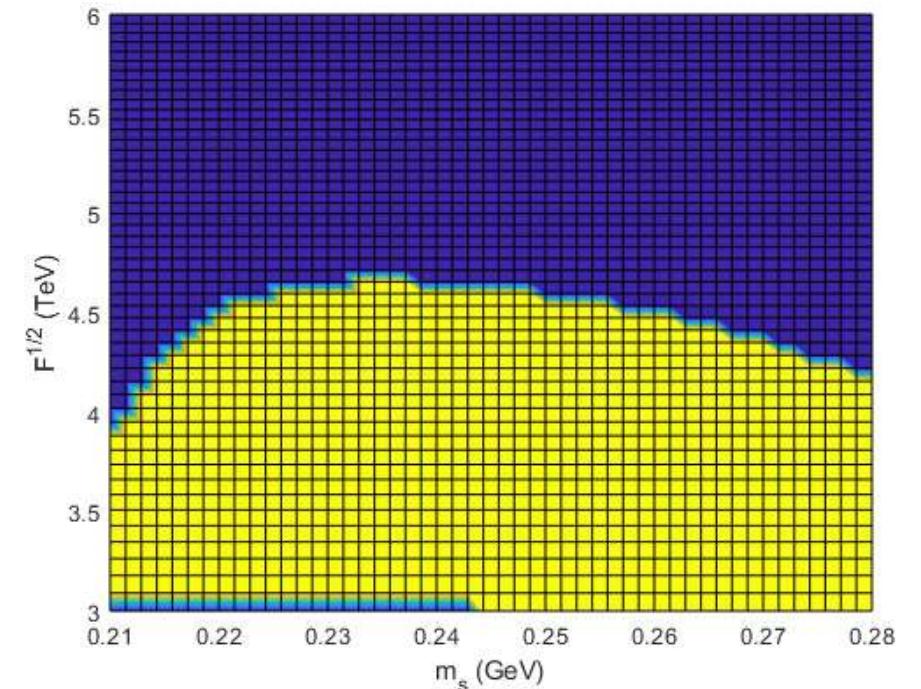
$$A_l = 5 \text{ TeV}$$

Soft parameters space (FASER1)

Source: Flavor violating meson decay (η) Decay: Lepton



$$A_l = 2 \text{ TeV}; m_F^{LR} = 1 \text{ GeV}$$



$$A_l = 3 \text{ TeV}; m_F^{LR} = 1 \text{ GeV}$$

Soft parameter space (FASER2) Meson

$$m_S < 4 \text{ GeV}$$

$$3 \text{ TeV} < \sqrt{F} < 7 \cdot 10^3 \text{ TeV}$$

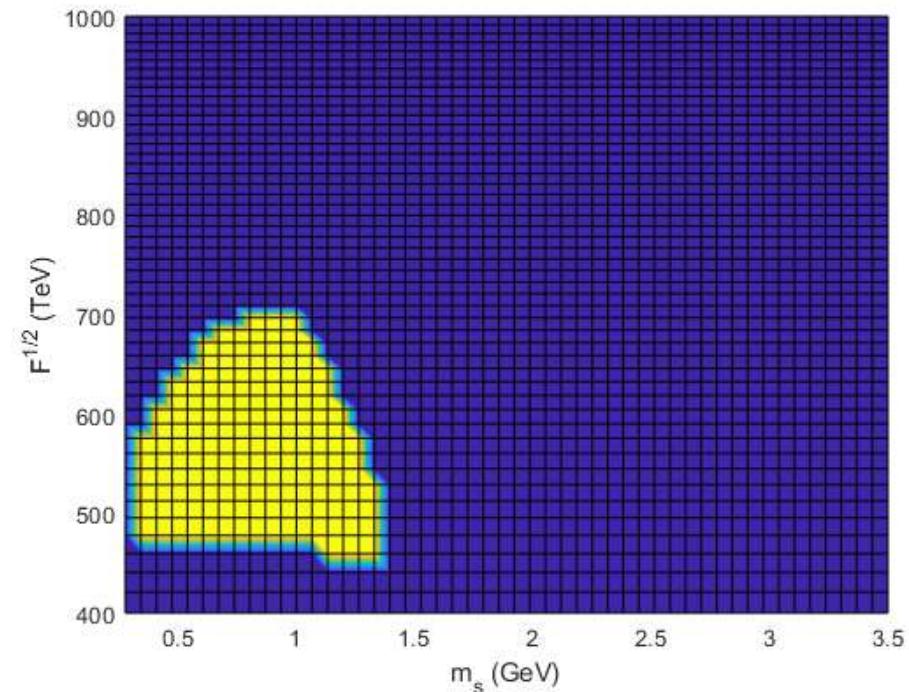
$$100 \text{ GeV} < A_Q < \sqrt{F}$$

$$3 \text{ TeV} < M_3 < \sqrt{F}$$

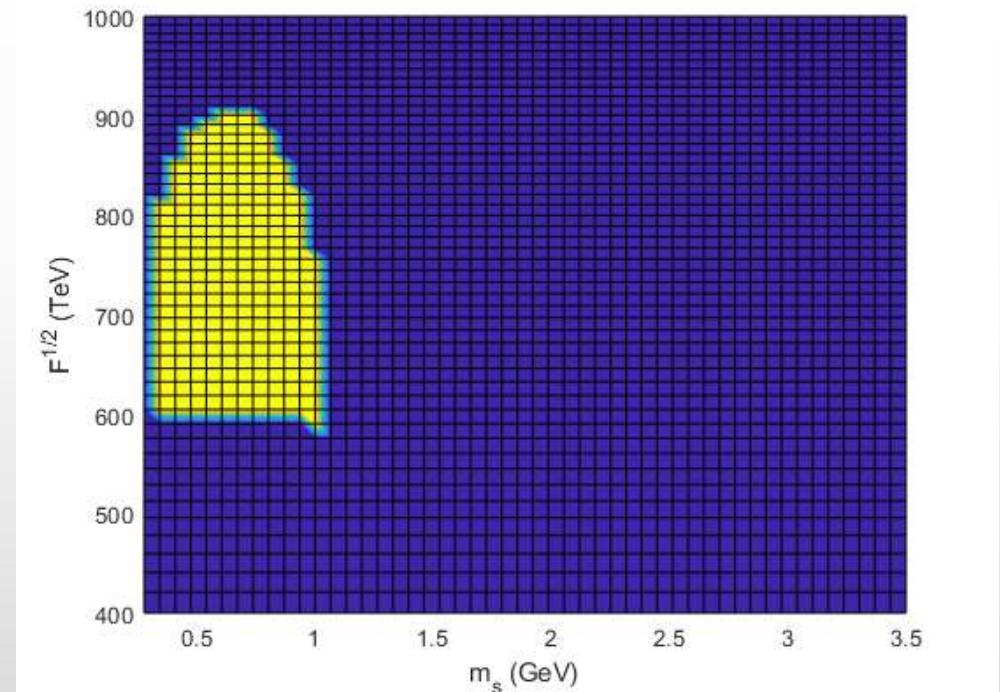
$$m_F^{LR}{}_{ij} < 100 \text{ GeV}$$

Soft parameters space (FASER2)

Source: Flavor conserving meson decay (B) Decay: Meson



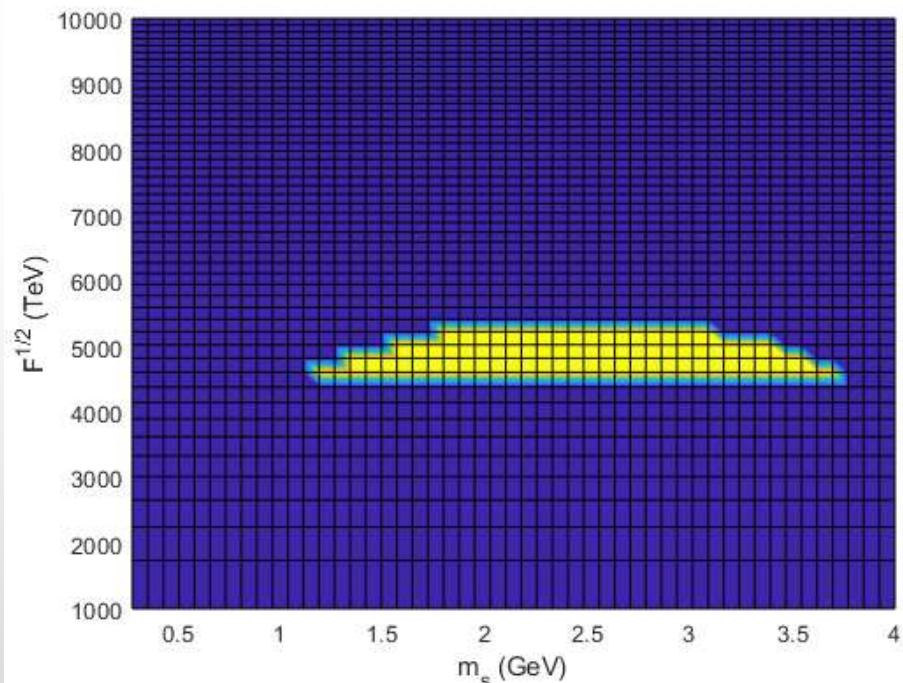
$$A_Q = 200 \text{ TeV}; M_3 = 3 \text{ TeV}$$



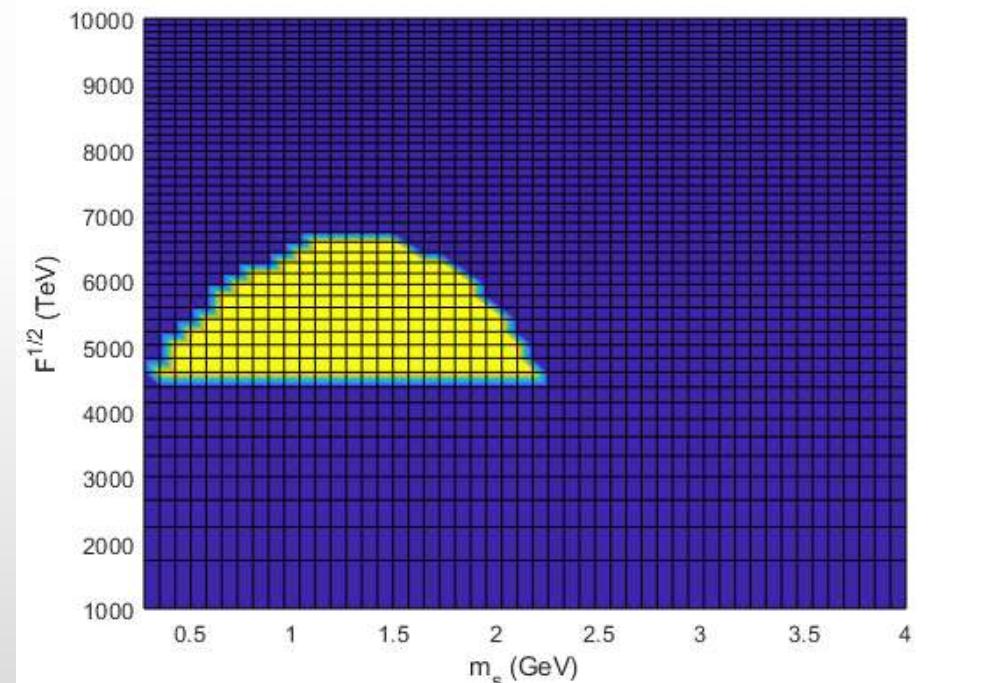
$$A_Q = 300 \text{ TeV}; M_3 = 10 \text{ TeV}$$

Soft parameters space (FASER2)

Source: Flavor violating meson decay (B) Decay: Meson



$$M_3 = 10 \text{ TeV}; m_F^{LR} = 100 \text{ GeV}$$



$$M_3 = 100 \text{ TeV}; m_F^{LR} = 100 \text{ GeV}$$

Soft parameters space (FASER1)

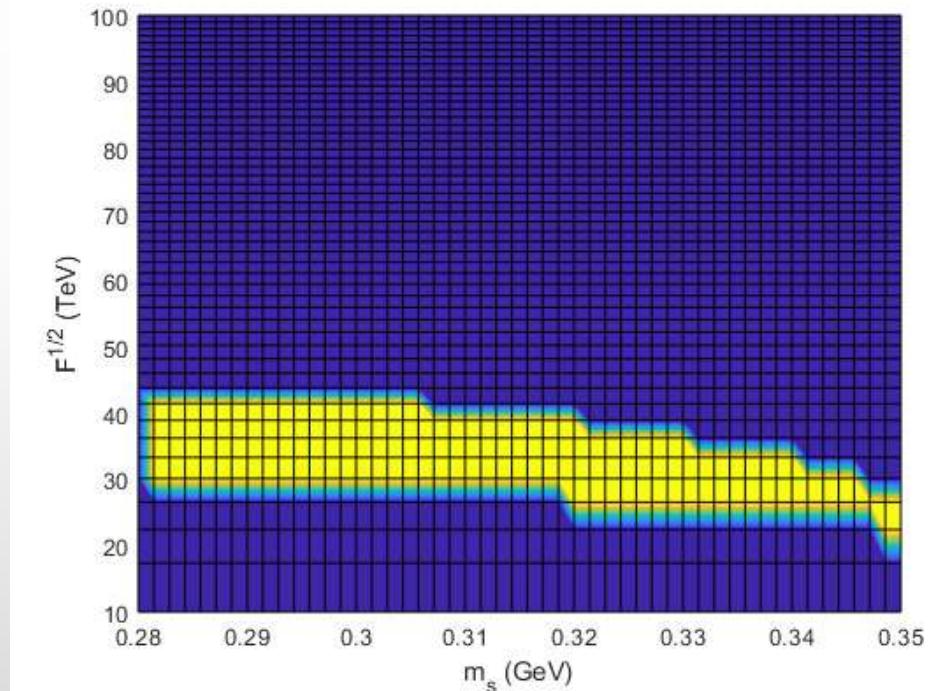
Source: Flavor violating meson decay (η) Decay: Meson

$$2m_\pi < m_s < 0.35 \text{ GeV}$$

$$10 \text{ TeV} < \sqrt{F} < 5 \cdot 10^2 \text{ TeV}$$

$$3 \text{ TeV} < M_3 < \sqrt{F}$$

$$10 \text{ GeV} < m_{F\ ij}^{LR} < 100 \text{ GeV}$$



$$m_{F\ ij}^{LR} = 10 \text{ GeV}$$

Summary

- Most promising sgoldstino mass: $m_s < 2m_\pi$
- Decaying into photons gives good possibility for detecting sgoldstino, but both photons should be recognized
- Muons will be divided by magnets in FASER, but muon decays gives strong restrictions on sgoldstino mass
- Meson decay is main signal for sgoldstino with masses above pion threshold
- e^+e^- channel is always open, but it is suppressed by lepton mass

Thank you for your attention