# Radiative Decay of sub-GeV Supersymmetric Neutralinos from Light Mesons

in collaboration with H. Dreiner, S. Nangia and Z. S. Wang

## 4th Forward Physics Facility Meeting

Dominik Köhler
Bethe Center for Theoretical Physics
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# Outline

- Neutralinos in RPV - MSSM
  - Decay of light Neutralinos
- Simulation of Neutralino Spectrum & Decay
- Benchmarks Scenarios
  - Results
- Conclusion

# Let There Be Light...Neutralinos

- Typically, robust mass bounds on SUSY spectrum:
  $\mathcal{O}\left(\text{few } 100\ GeV\right) - \mathcal{O}\left(\text{few } TeV\right)$

- One interesting exception:
  Bino-like lightest neutralino $\tilde{\chi}_1^0$ -> can evade all collider mass limits!

  Cosmology:
  Dark matter bounds would imply:
  $M_{\tilde{\chi}_1^0} \geq \mathcal{O}\,(3 - 20\ GeV)$ -> unstable $\tilde{\chi}_1^0$ can escape this too! [arXiv:0707.1425]

# RPV-SUSY in (Very) Short

- Minimal SUSY superpotential:

$$W_{\mathrm{MSSM}} + W_{\mathrm{BNV}} + W_{\mathrm{LNV}}$$

$$W_{\mathrm{BNV}} = \frac{1}{2}\lambda''^{ijk}\bar{U}_i\bar{D}_j\bar{D}_k \qquad W_{\mathrm{LNV}} = \frac{1}{2}\lambda^{ijk}L_iL_j\bar{E}_k + \lambda'^{ijk}L_iQ_j\bar{D}_k + \kappa^i H_u L_i$$

-> RPV terms

- RPV usually put to 0 in MSSM to protect proton!
  But not necessary! Can protect proton in other ways.

- RPV is equally well-motivated and changes SUSY pheno drastically!

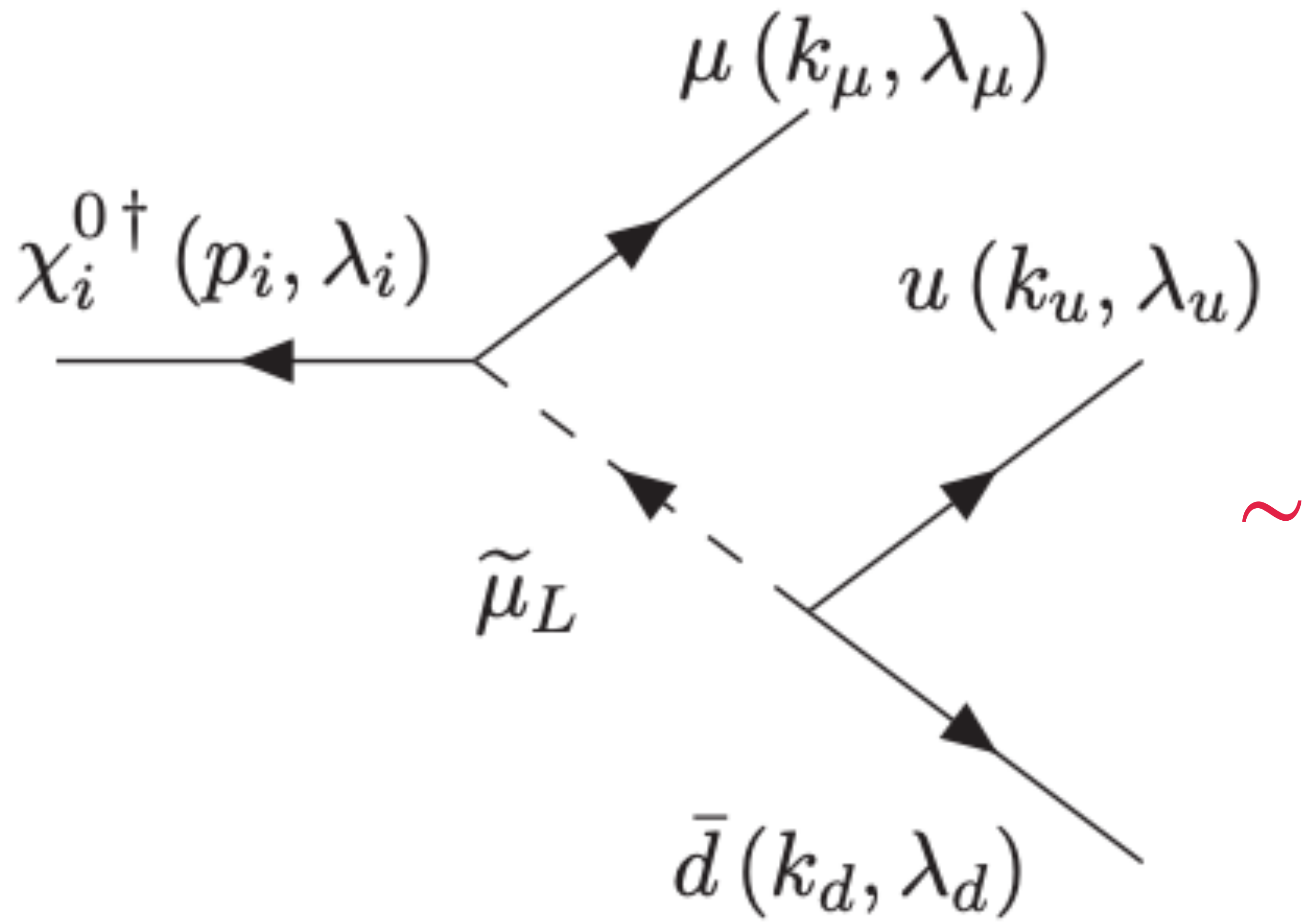
->Most interesting for us, LSP no longer stable: $\tilde{\chi}_1^0$ can be very light, and long-lived!

# Light(-est $\tilde{\chi}_1^0$) means Photons!

- The typical $\tilde{\chi}_1^0$ in RPV decays at tree-level:

  LQD: e.g., $\tilde{\chi}_1^0 \rightarrow M^+ + l^-$

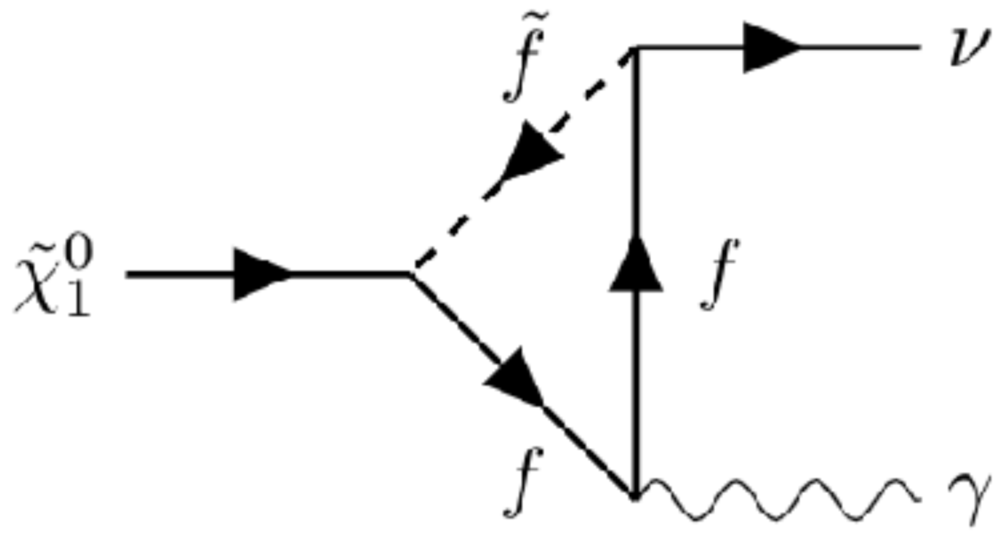
  LLE: e.g., $\tilde{\chi}_1^0 \rightarrow l^+ + l^- + \nu$ [arXiv:2008.07539]



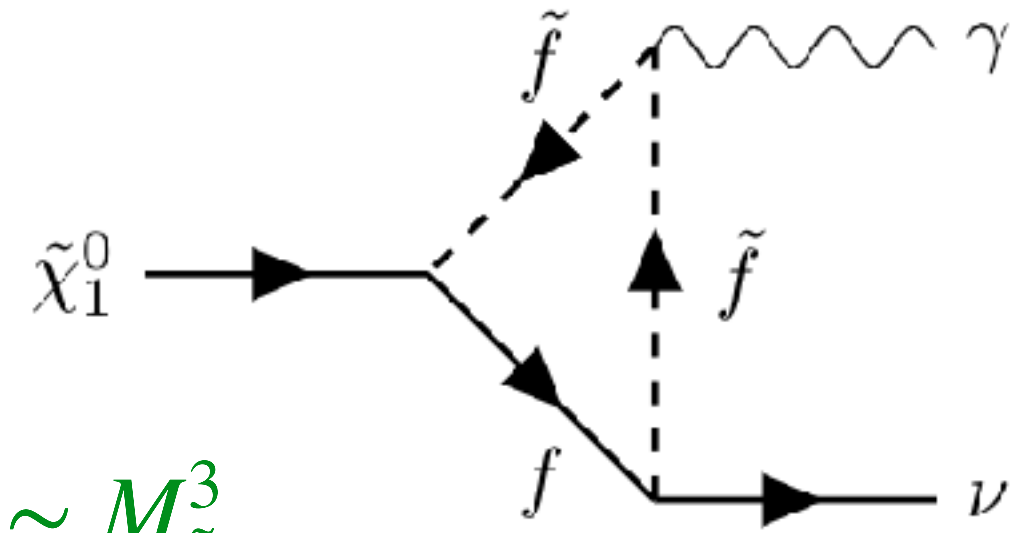

[arXiv:0812.1594]

$\sim M_{\tilde{\chi}}^5$

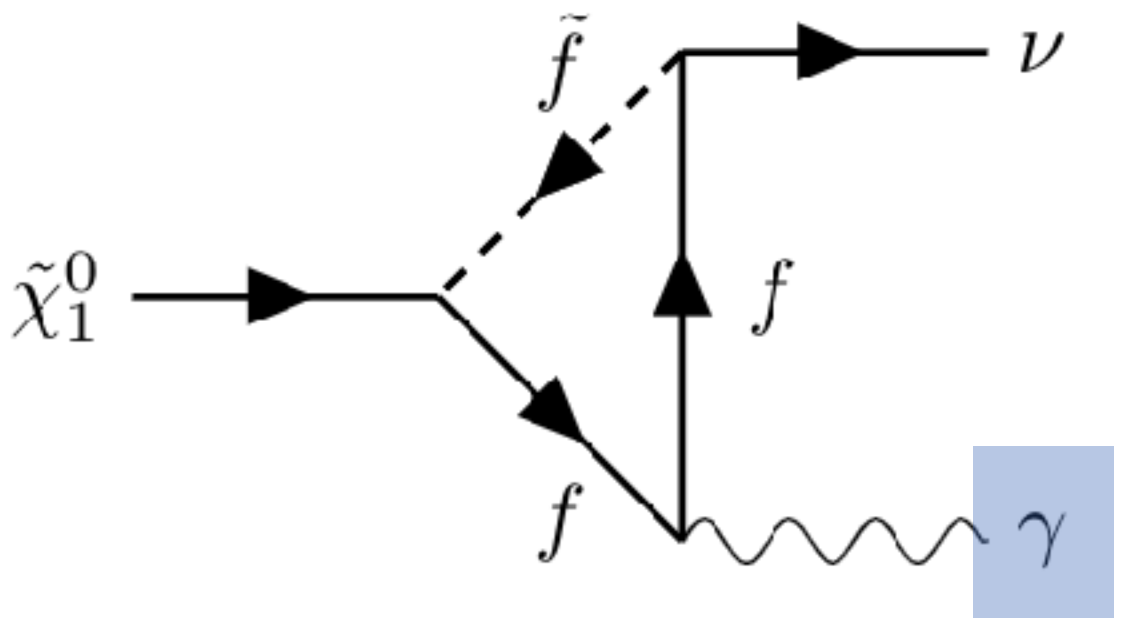
- But, if very light, kinematics/dynamic suppression may only allow loop-level mode: $\tilde{\chi}_1^0 \rightarrow \gamma + \nu$

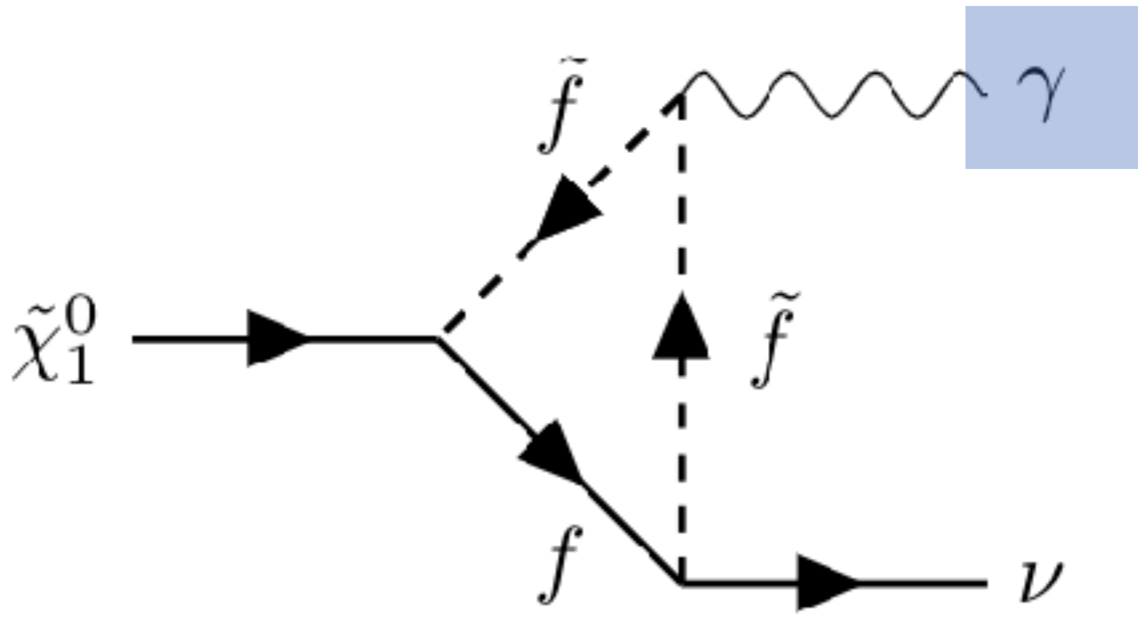



$\sim M_{\tilde{\chi}}^3$



# Single Photons at FASER




- Production of Neutralino in light meson decays
- Light, long-lived -> boosted $\gamma$ in far-forward region -> FASER, FASER2 ideal

[arXiv:2011.04751] & thanks to Felix Kling!

- Single photon signature:

-> See as energy deposit in EM calorimeter: Pre-shower station helps identify photon

-> BG1: $\mu$ Bremsstrahlung - FASER muon veto

-> BG2: $\nu$ cc interactions in detector producing $\gamma$ - with $\sim \mathcal{O}(10)$ charged tracks

-> can reject BG with high efficiency!!

# Simulation with FORESEE

[arXiv:2105.07077] & thanks to Felix Kling and Sebastian Trojanowski!

- Forward spectra of SM mesons available at hand
- Light mesons decay according to $N^{\text{prod}}_{M\tilde{\chi}^0_1} = N_M \tau_M \Gamma(M^{(*)}_{jk} \rightarrow \tilde{\chi}^0_1 + l_i)$
- Light particles inherit in forward direction: Contains momentum & angular distribution of produced Neutralinos
- Simulate Neutralino decay via model-(in)dependent decay lengths
- Adjust the detector geometry, the search type & cuts fitting for FASER and FASER2:

| Collider | Luminosity $\mathcal{L}$ | Energy | Distance $L$ | Detector Length $\Delta$ | Detector Radius $R$ |
|---|---|---|---|---|---|
| FASER, LHC | 150 $\text{fb}^{-1}$ | 14 TeV | 480 m | 1.5 m | 10 cm |
| FASER 2, HL-LHC | 3000 $\text{fb}^{-1}$ | 14 TeV | 480 m | 5 m | 1 m |

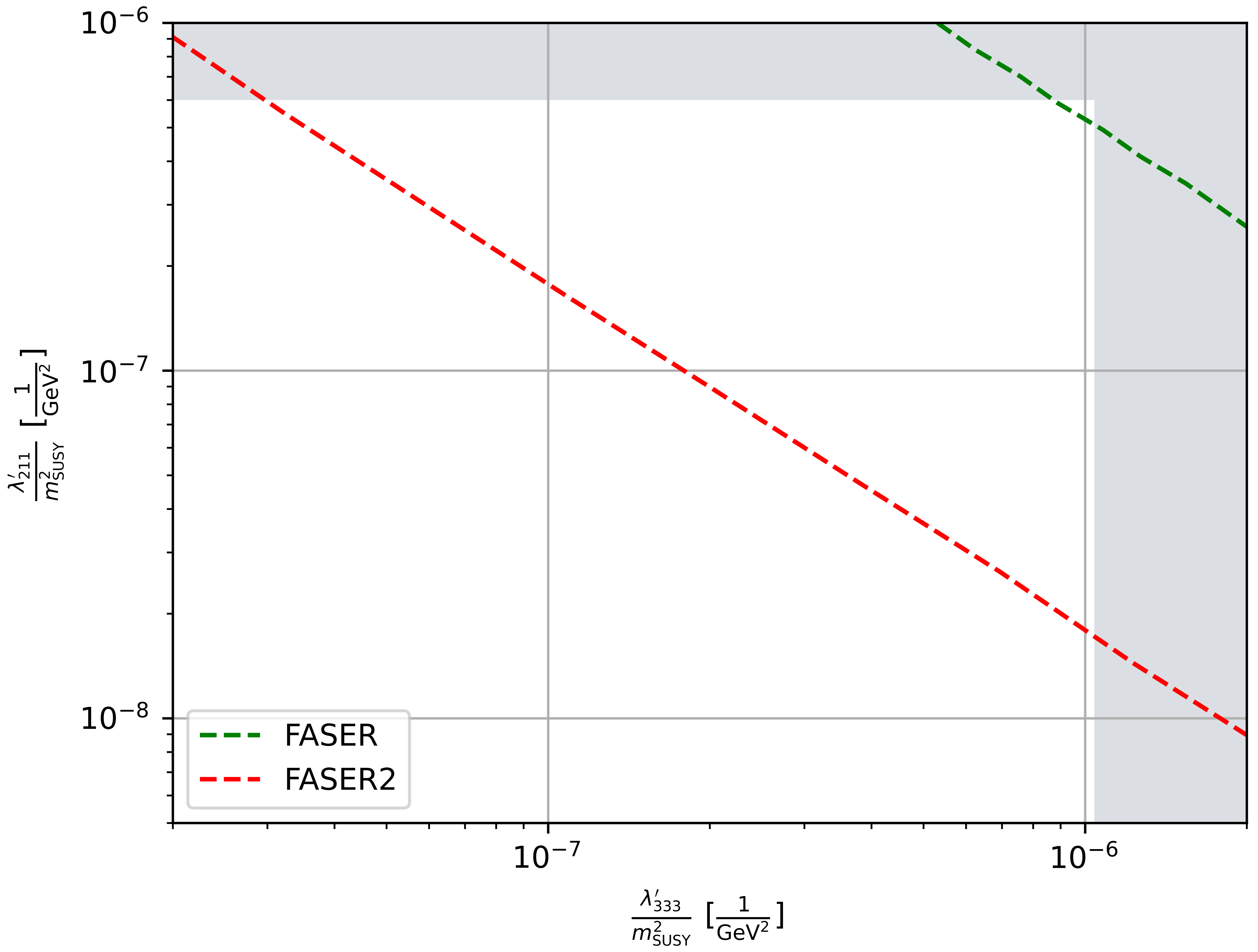
# Benchmark Scenarios

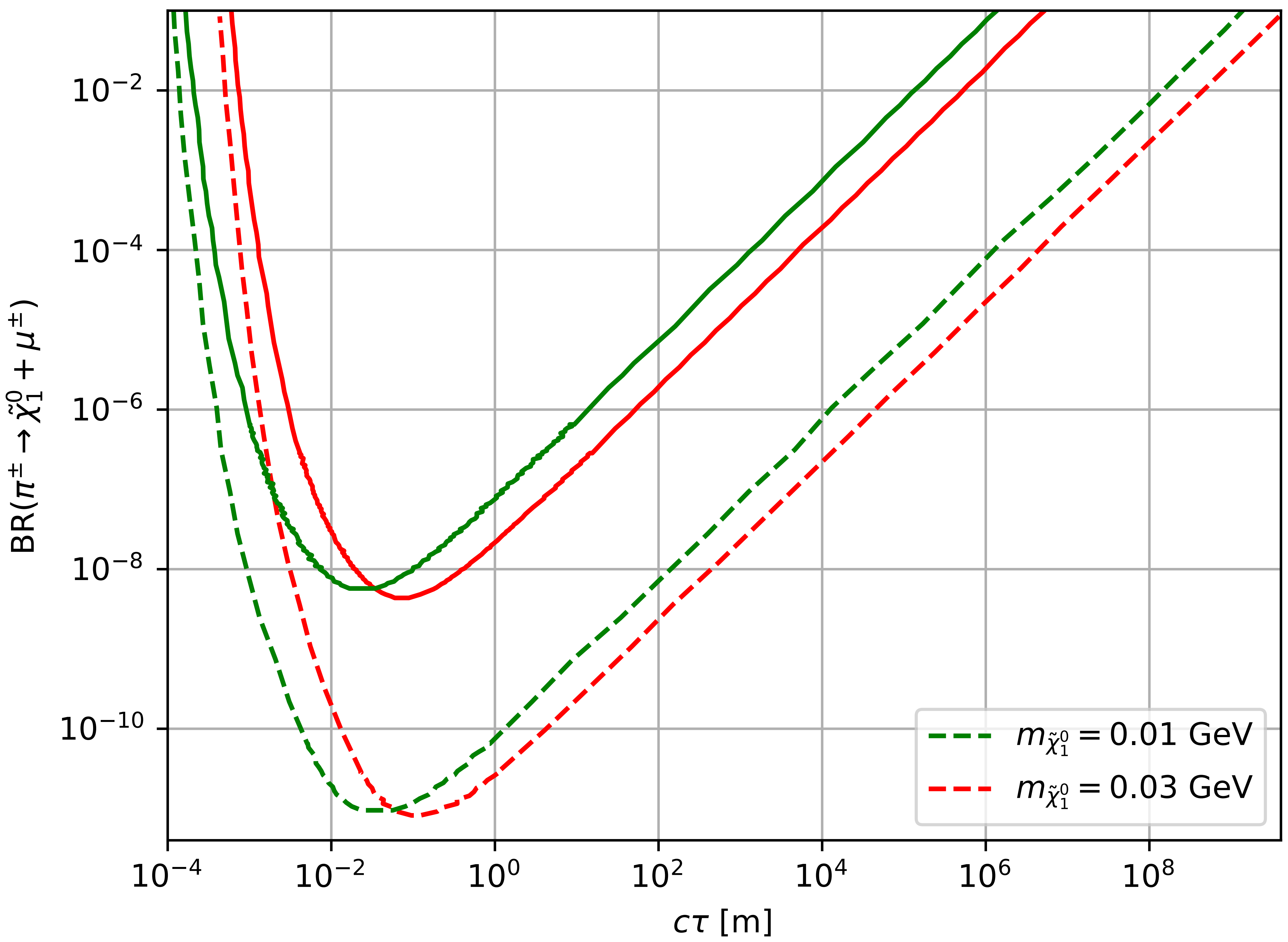
| Scenario | $\mathbf{M}_{\tilde{\chi}_1^0}$ | Production $\left(\lambda^{\mathrm{P}}_{ijk}\right)$ | Decay $\left(\lambda^{\mathrm{D}}_{ijj}\right)$ | Current Constraints |
|---|---|---|---|---|
| **B1** | $30\,\mathrm{MeV}$ | $\lambda'_{211}\left(M=\pi^{\pm},\pi^0\right)$ | $\lambda'_{333}$ | $\lambda'_{211}<0.59\left(\frac{m_{\tilde{d}_R}}{1\,\mathrm{TeV}}\right),\lambda'_{333}<1.04$ |
| **B2** | $200\,\mathrm{MeV}$ | $\lambda'_{112}\left(M=K^{\pm},K^0_{L/S}\right)$ | $\lambda_{322}$ | $\lambda'_{112}<0.21\left(\frac{m_{\tilde{s}_R}}{1\,\mathrm{TeV}}\right),\lambda_{322}<0.7\left(\frac{m_{\tilde{\mu}_R}}{1\,\mathrm{TeV}}\right)$ |
| **B3** | $500\,\mathrm{MeV}$ | $\lambda'_{222}\left(M=D_S^{\pm}\right)$ | $\lambda'_{222}$ | $\lambda'_{222}<1.12$ |

- Scenarios can probe different couplings and mass regions
- Assume RPV coupling for both production and decay
- FASER can explore open parameter space for RPV-SUSY

# $\pi^{\pm}, \pi^0 \rightarrow \tilde{\chi}_1^0 + X$

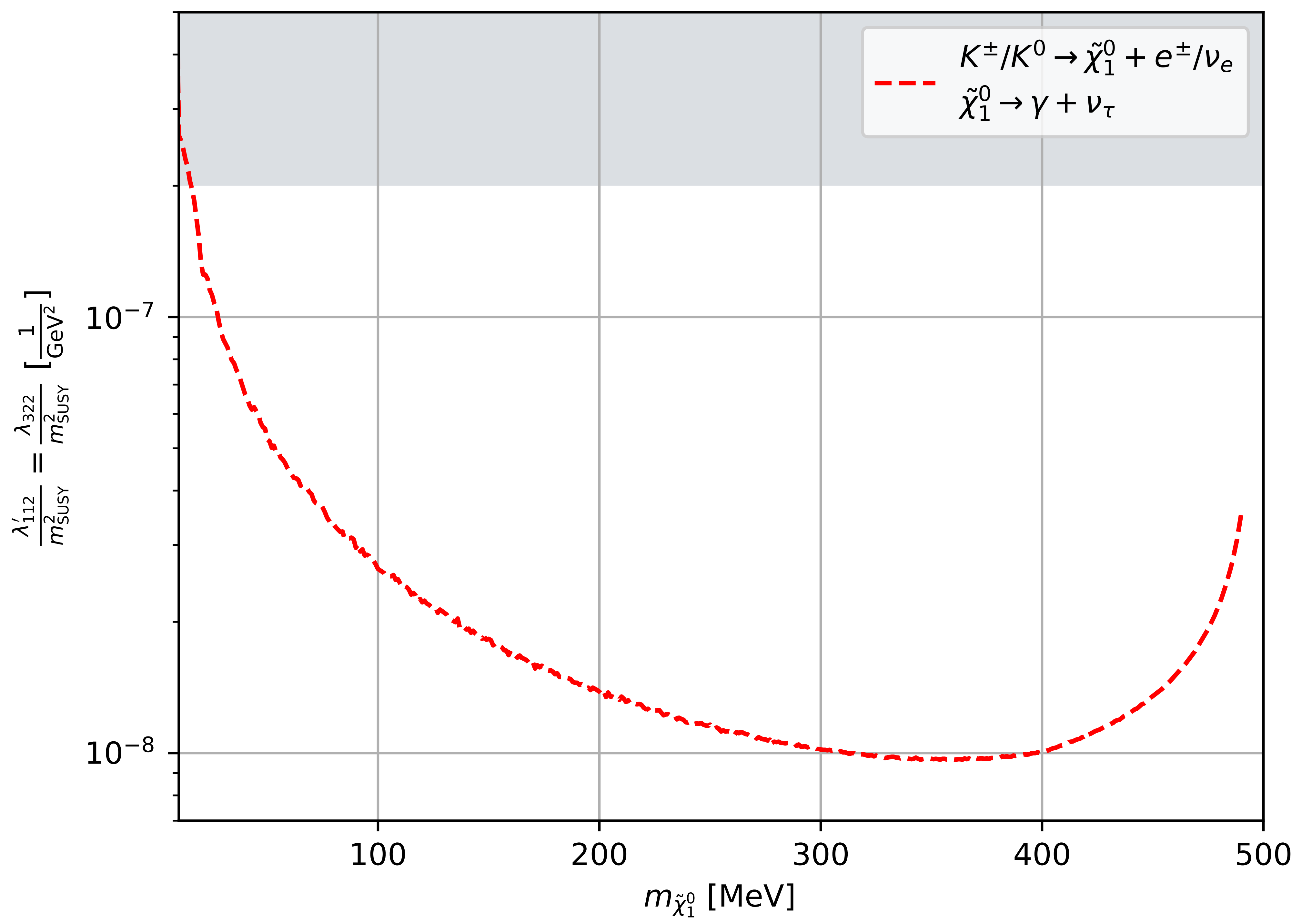
- Can probe very light Neutralinos
- Production: $\lambda'_{211}$ (LQD 211)
- Decay: $\lambda'_{333}$ (LQD 333)

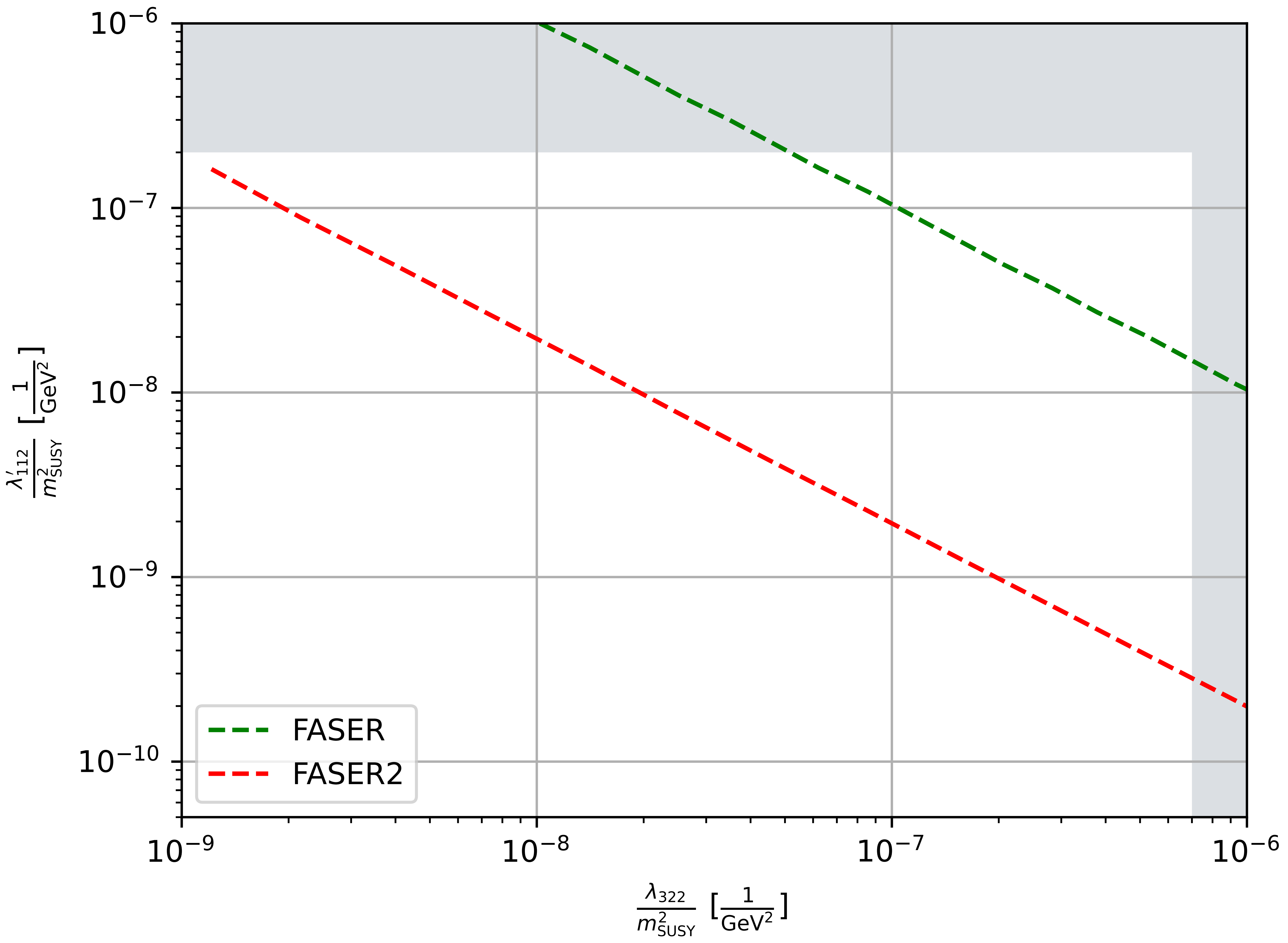


# $K^{\pm}, K^0_{L/S} \rightarrow \tilde{\chi}^0_1 + X$

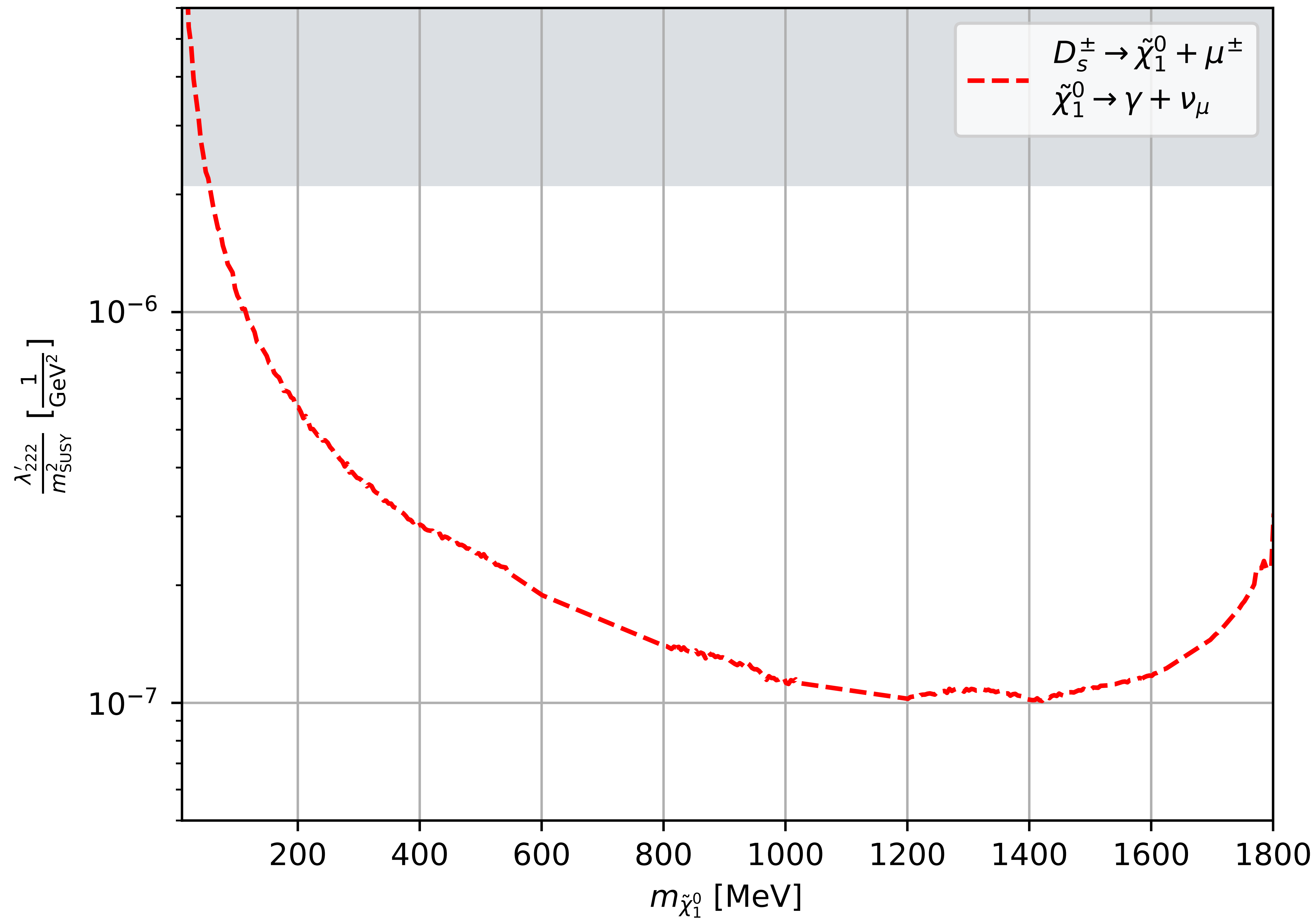
- Probe existing constraints for wide mass range
- Production: $\lambda'_{112}$ (LQD 112)
- Decay: $\lambda_{322}$ (LLE 322)

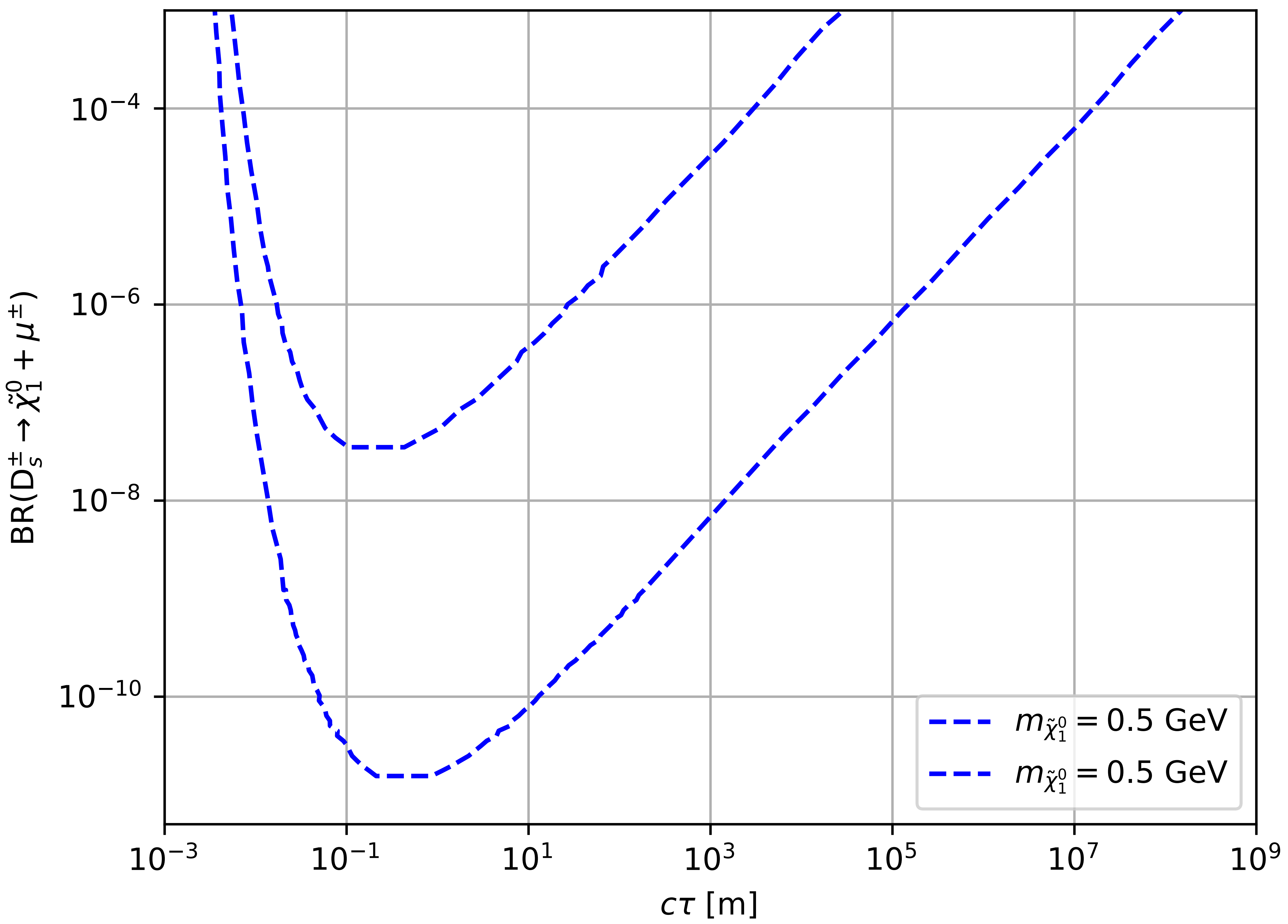


# $D_s^{\pm} \rightarrow \tilde{\chi}_1^0 + \mu^{\pm}$

- Neutralino can be produced and decay via same coupling
- Production/Decay: $\lambda'_{222}$ (LQD 222)



# Conclusion & Outlook

- RPV SUSY models provide a possibility of a light neutralino can be searched in Far Forward Detectors
- New search via radiative decay: $\gamma + \nu$
- FASER can already exceed current (collider) bounds on RPV SUSY
- FASER2 can probe even a wider range of parameter space for a variety of models