

# Searching for low-mass LLPs from strongly interacting dark sectors

Patrick Tunney

in collaboration with: Elias Bernreuther, Juliana Carrasco Mejia,  
Felix Kahlhoefer, Micheal Kramer

**Based on arXiv:20xx.xxxxx**



# Outline

- Our SIMP model set-up, with a  $Z'$  portal to the SM
- Key signature: dark showers with an LLP decaying visibly
- Existing ATLAS search for displaced vertices and missing energy
- Possible new searches with relaxed cuts

Strongly interacting dark sector:  $SU(3)_d$

Dark QCD charges:  $N_d = 3$

Dark flavours:  $N_f = 2$

Confinement  $\Lambda_d$



Dark Matter:  $\pi^0, \pi^\pm$

Dark Mesons:  $\rho^0, \rho^\pm$

(These are exotic mesons, not SM particles...)

**Portal to SM:  $U(1)'$**

$$\mathcal{L} \supset e_d Z'_\mu \bar{q}_d \gamma^\mu q_d + g_q Z'_\mu q_{\text{SM}} \bar{q}_{\text{SM}} \gamma^\mu q_{\text{SM}}$$

→ Dark quark production at LHC from SM quarks (similar to Drell-Yan)

$Z'$  mixes with exotic  $\rho^0$

→ Induces couplings of  $\rho^0$  to SM quarks

$$\mathcal{L}_{\text{EFT}} \supset \frac{2 e_d g_q}{g} \frac{m_\rho^2}{m_{Z'}^2} \rho^{0\mu} \sum_{q_{\text{SM}}} \bar{q}_{\text{SM}} \gamma_\mu q_{\text{SM}}$$

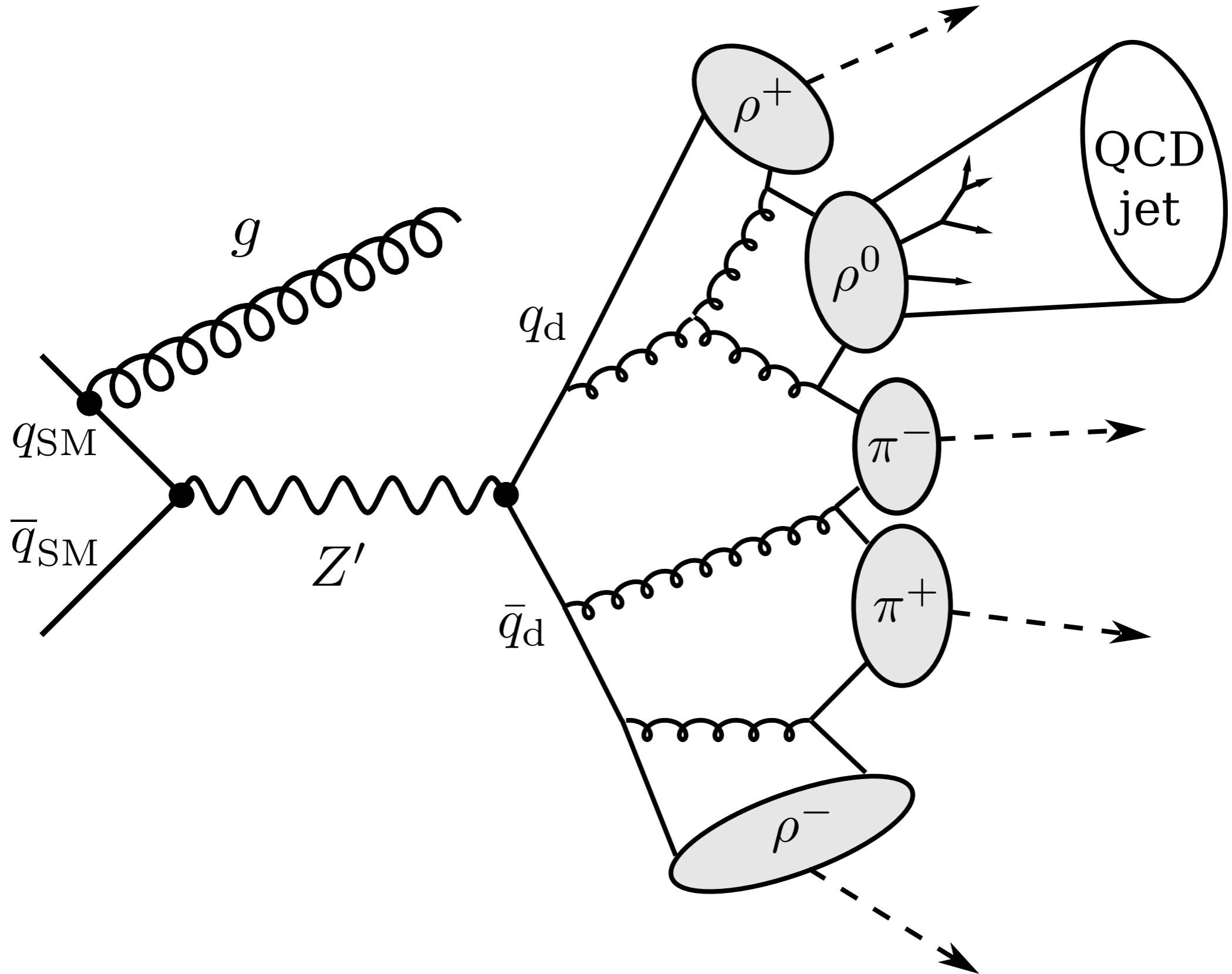
$\rho^0$  long-lived

Decay is purely to SM quarks  $\rho^0 \rightarrow q_{\text{SM}} q_{\text{SM}}$

$$\Gamma(\rho^0 \rightarrow q_{\text{SM}} \bar{q}_{\text{SM}}) = \frac{1}{\pi} \frac{g_q^2 e_d^2}{g^2} m_\rho \left( \frac{m_\rho}{m_{Z'}} \right)^4 \left( 1 - 4 \frac{m_{q_{\text{SM}}}^2}{m_\rho^2} \right)^{1/2} \left( 1 + 2 \frac{m_{q_{\text{SM}}}^2}{m_\rho^2} \right)$$

$$c\tau_\rho \approx 3.2 \text{ mm} \times \left( \frac{g_q}{0.01} \right)^{-2} \left( \frac{e_d}{0.4} \right)^{-2} \left( \frac{m_\rho}{5 \text{ GeV}} \right)^{-5} \left( \frac{m_{Z'}}{1 \text{ TeV}} \right)^4$$

For more model details see [arXiv:1907.04346](https://arxiv.org/abs/1907.04346)



## ATLAS DV+MET search, $L = 32.8 \text{ fb}^{-1}$

### Tracks:

- The track originates from a stable and charged particle
- The track has  $p_T > 1 \text{ GeV}$
- The particle has a transverse impact parameter  $d_0 > 2 \text{ mm}$ .

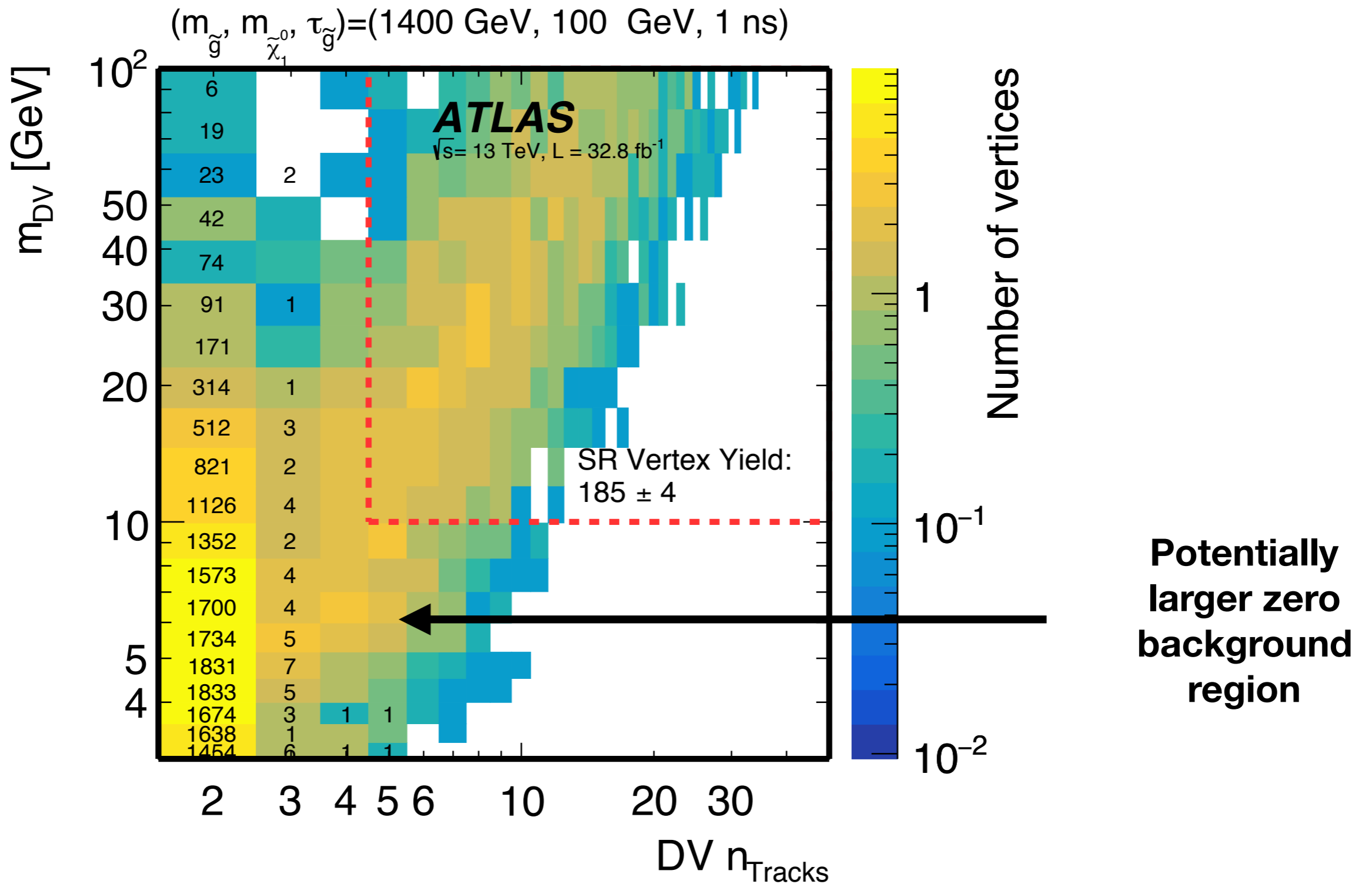
### Displaced Vertices (DVs):

- The DV position must satisfy  $4 \text{ mm} < R < 300 \text{ mm}$  and  $|z| < 300$ .
- The number of tracks associated to a particular DV  $n_{\text{tracks}} \geq 5$ .
- The DV mass  $m_{\text{DV}} > 10 \text{ GeV}$ .

### Events:

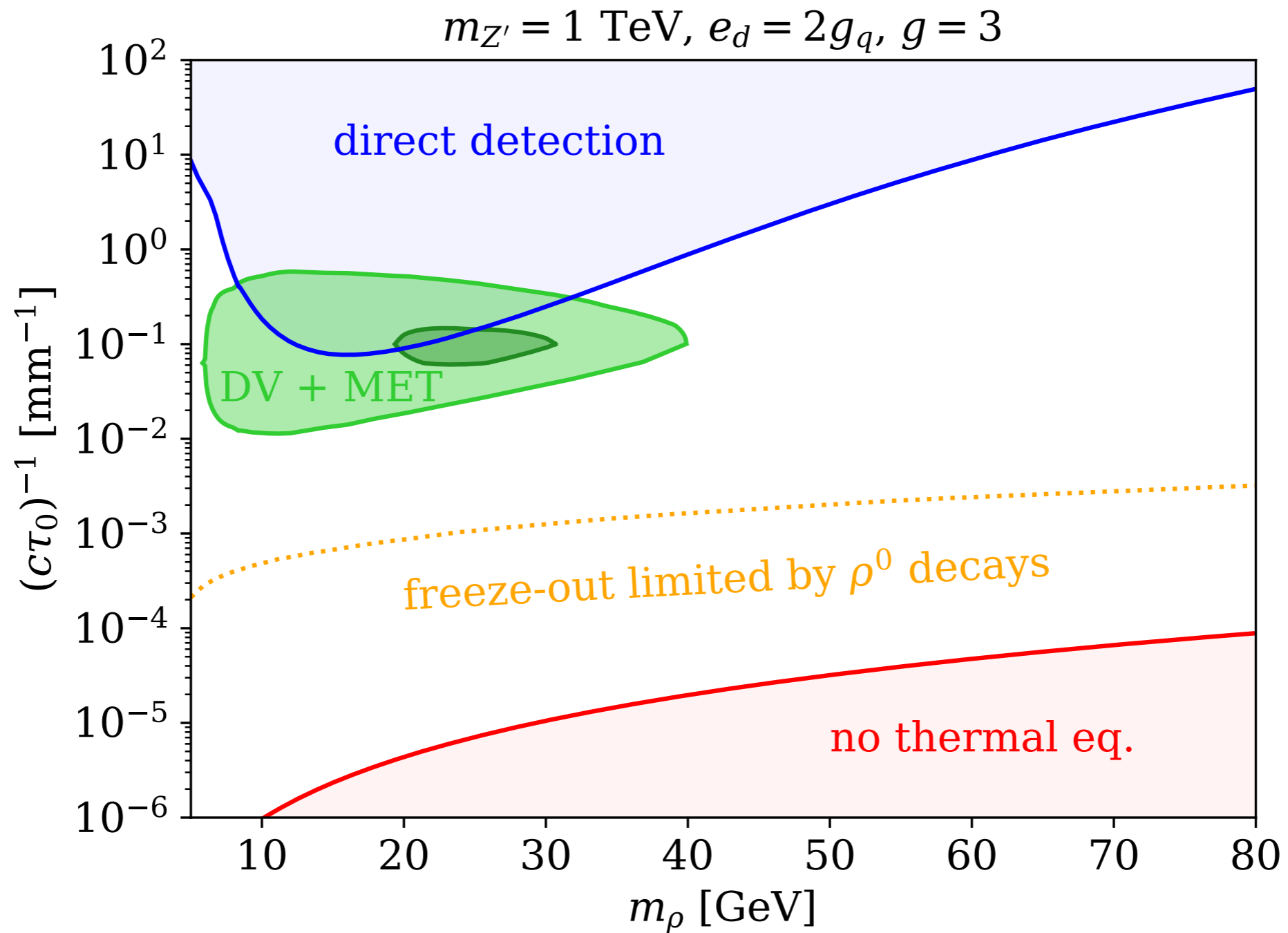
- Missing energy  $E_T^{\text{miss}} > 200 \text{ GeV}$ .
- 75% of the events should have at least one jet with  $p_T > 70 \text{ GeV}$  or at least two jets with  $p_T > 25 \text{ GeV}$ .

**arXiv:1710.04901**



[arXiv:1710.04901](https://arxiv.org/abs/1710.04901)

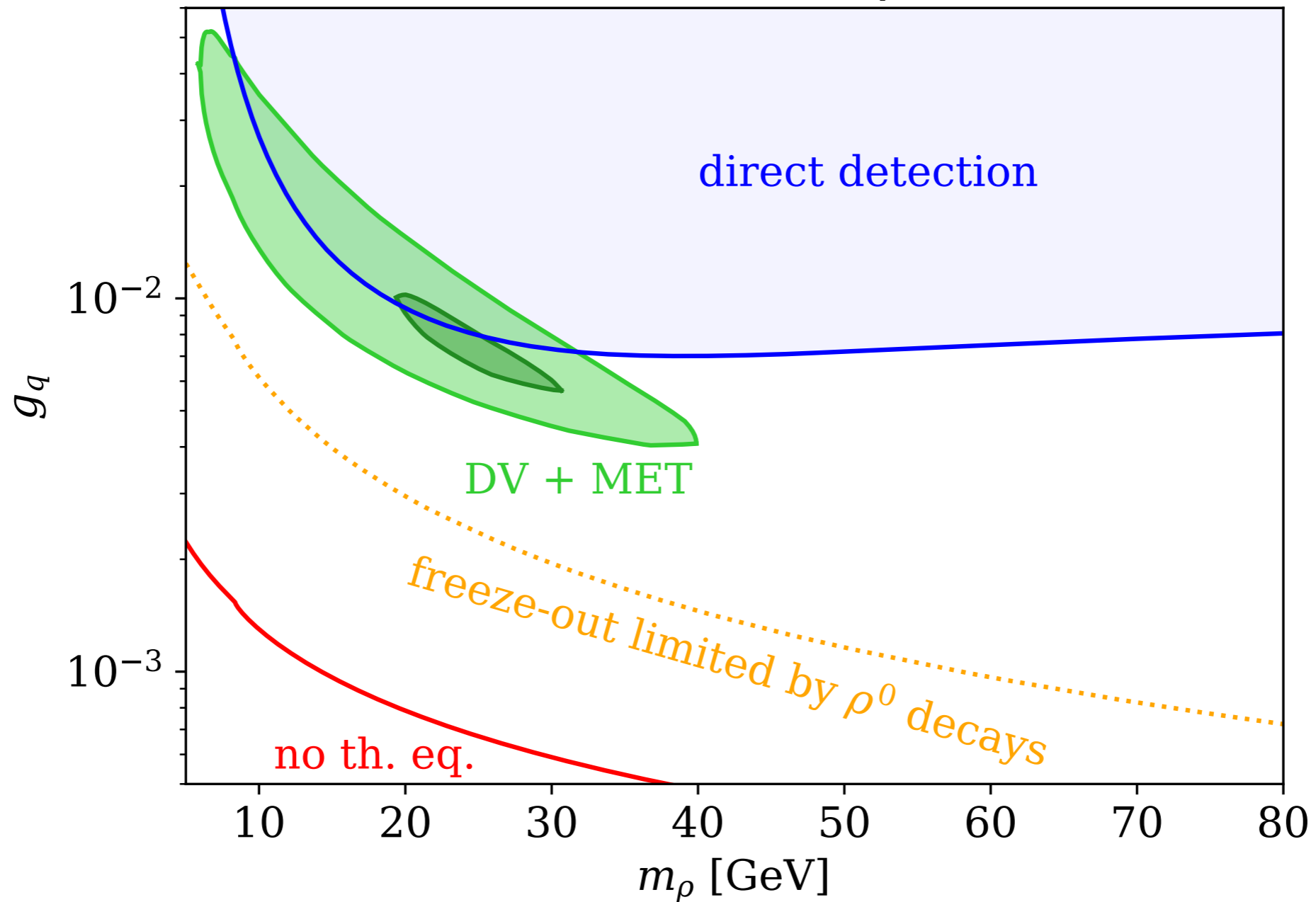




**Existing analysis:**  $m_{\text{DV}} > 10 \text{ GeV}, n_{\text{tracks}} \geq 5$

**Relaxed analysis:**  $m_{\text{DV}} > 5 \text{ GeV}, n_{\text{tracks}} \geq 4$

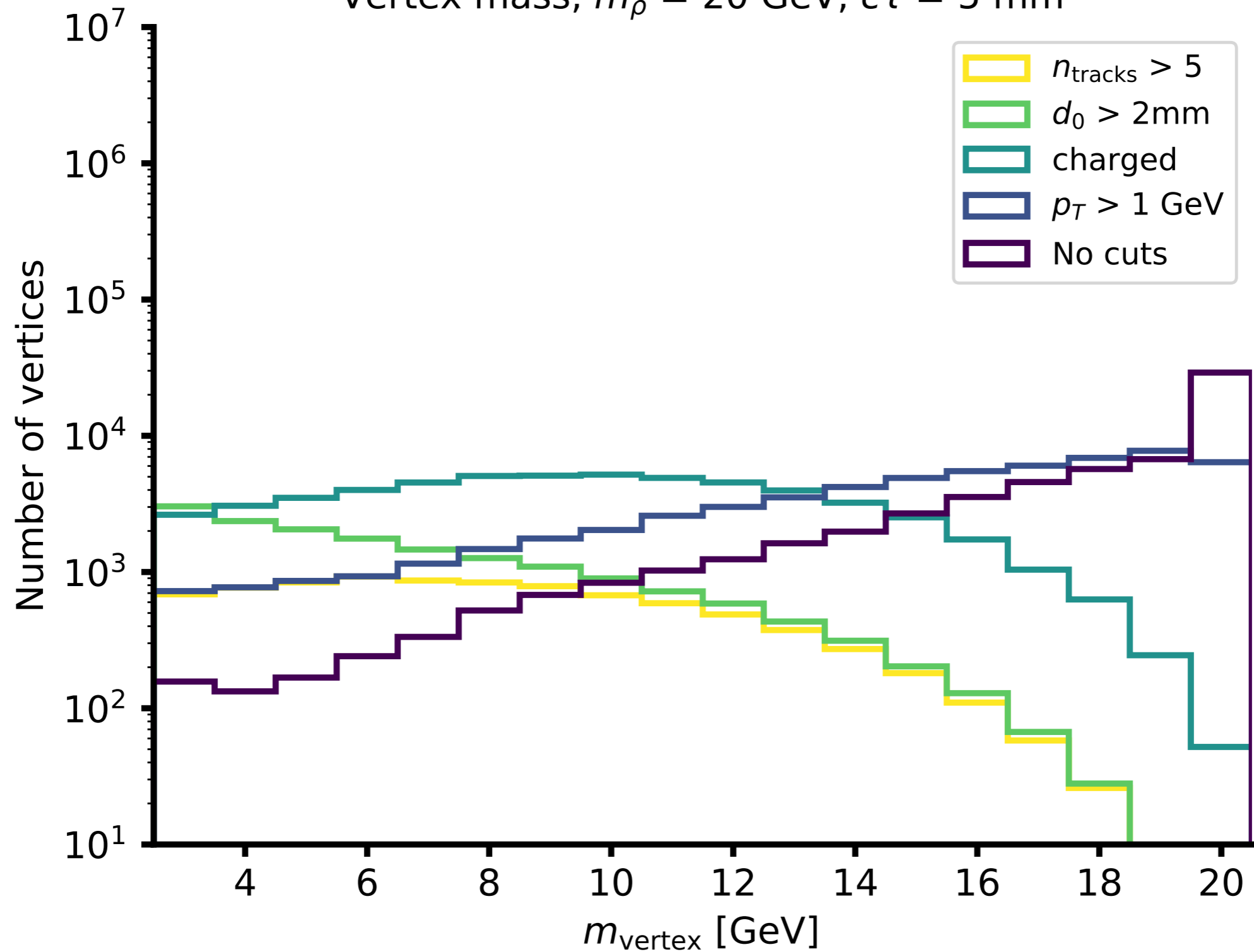
$$m_{Z'} = 1 \text{ TeV}, e_d = 2g_q, g = 3$$



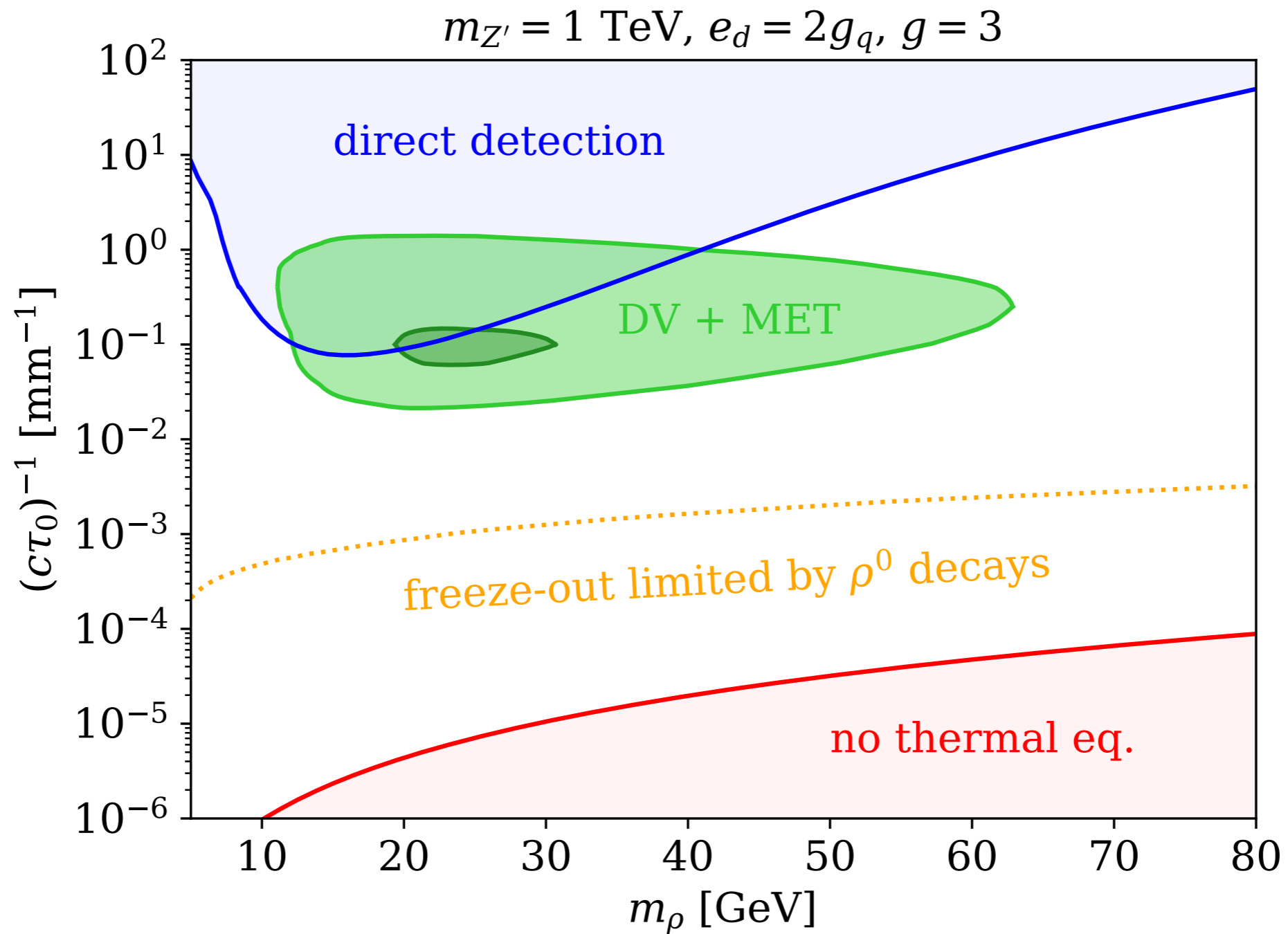
**Existing analysis:**  $m_{\text{DV}} > 10 \text{ GeV}, n_{\text{tracks}} \geq 5$

**Relaxed analysis:**  $m_{\text{DV}} > 5 \text{ GeV}, n_{\text{tracks}} \geq 4$

Vertex mass,  $m_\rho = 20 \text{ GeV}$ ,  $c\tau = 5 \text{ mm}$



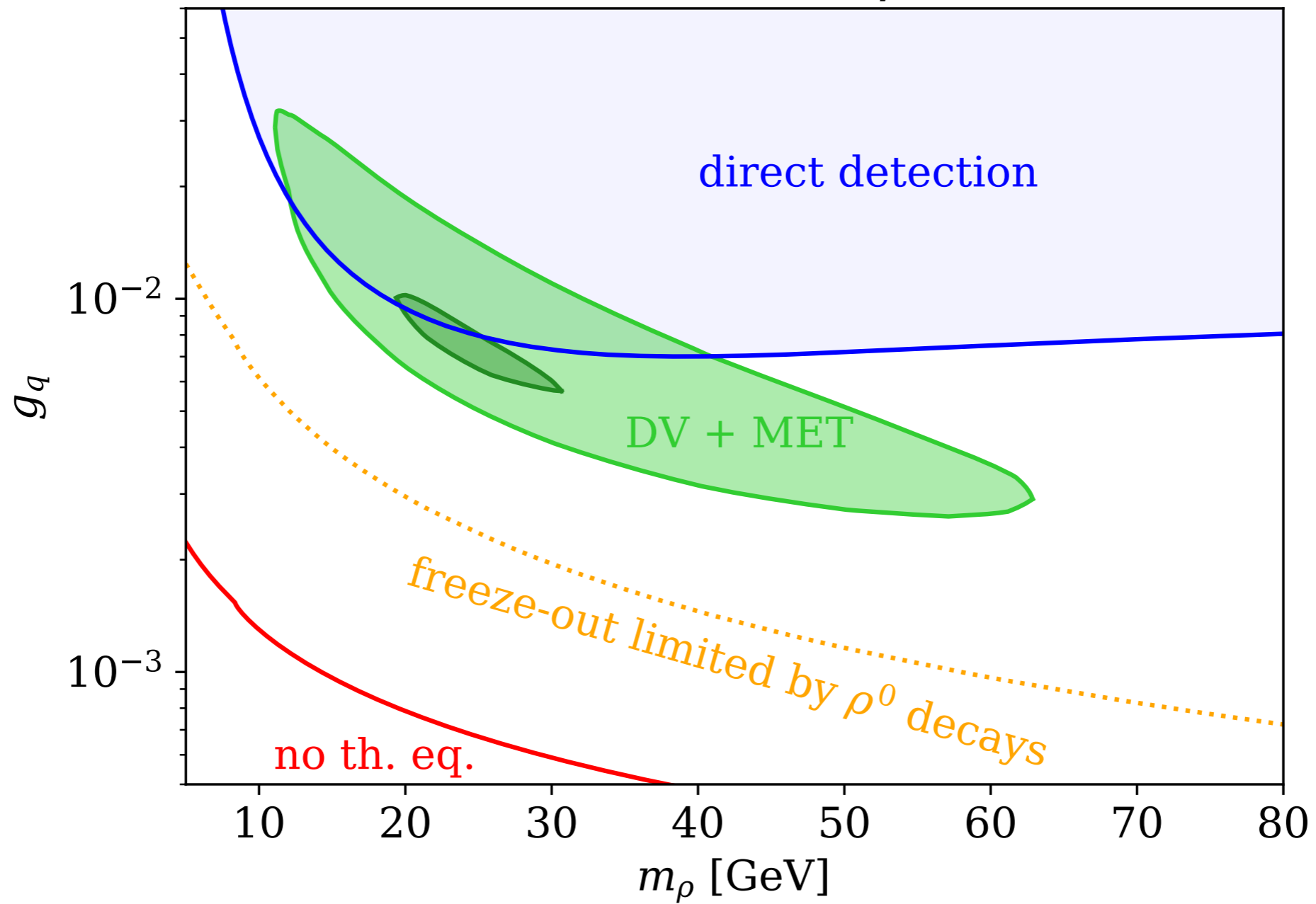
→ Track requirements reduce the observed vertex mass



**Existing analysis: all tracks  $d_0 > 2\text{mm}$**

**Relaxed analysis: 2 (or more) tracks  $d_0 > 2\text{mm}$**

$$m_{Z'} = 1 \text{ TeV}, e_d = 2g_q, g = 3$$



**Existing analysis: all tracks  $d_0 > 2\text{mm}$**

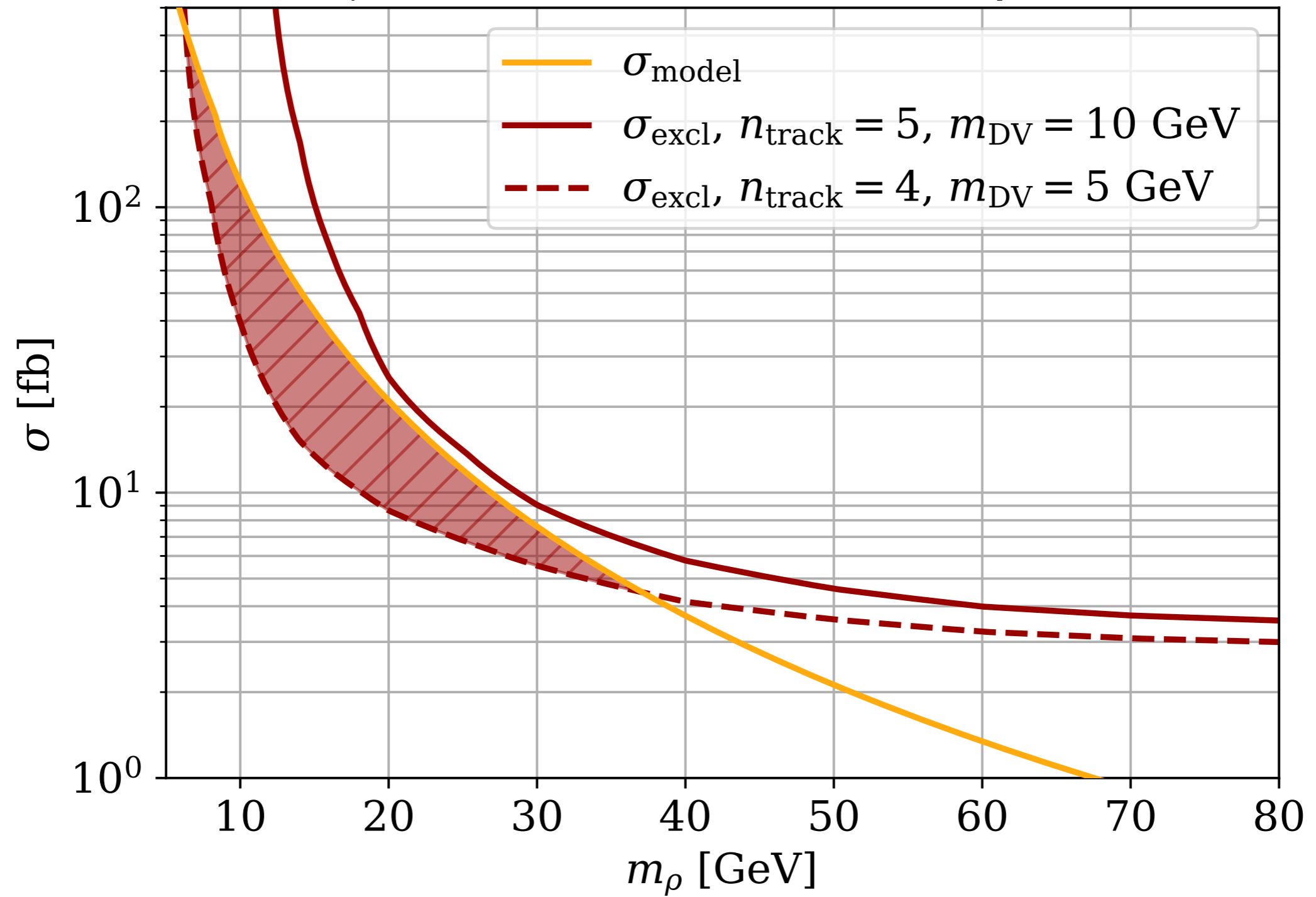
**Relaxed analysis: 2 (or more) tracks  $d_0 > 2\text{mm}$**

# Conclusions

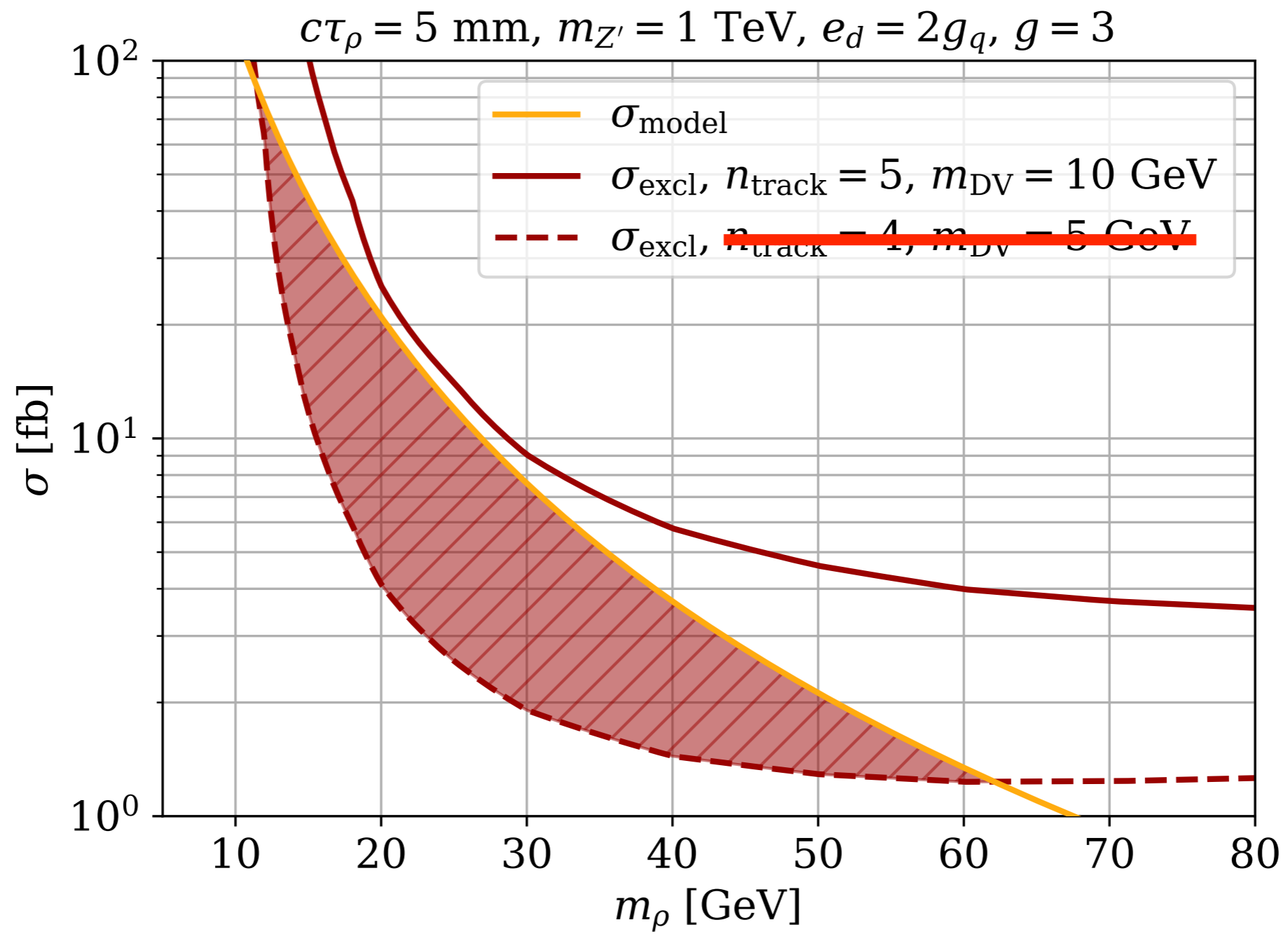
- Dark showers are an interesting source of LLPs
- Existing searches tend to target higher masses
- New effort required to explore 10 GeV and lower masses
- Relaxed searches are possible targets, but also non-zero background regions, multiple vertices in one event...

**BACKUP**

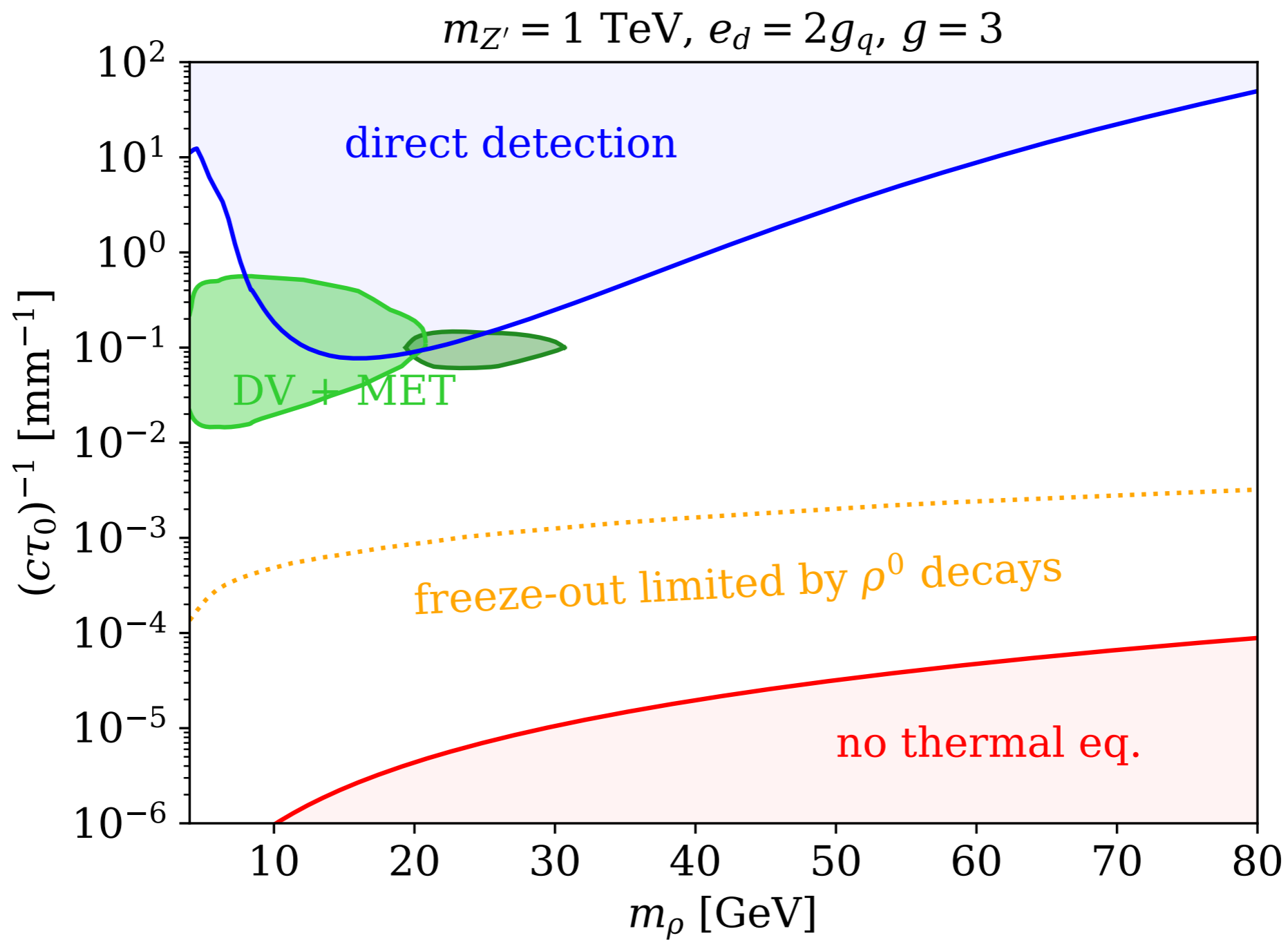
$c\tau_\rho = 5 \text{ mm}, m_{Z'} = 1 \text{ TeV}, e_d = 2g_q, g = 3$







relaxed d0

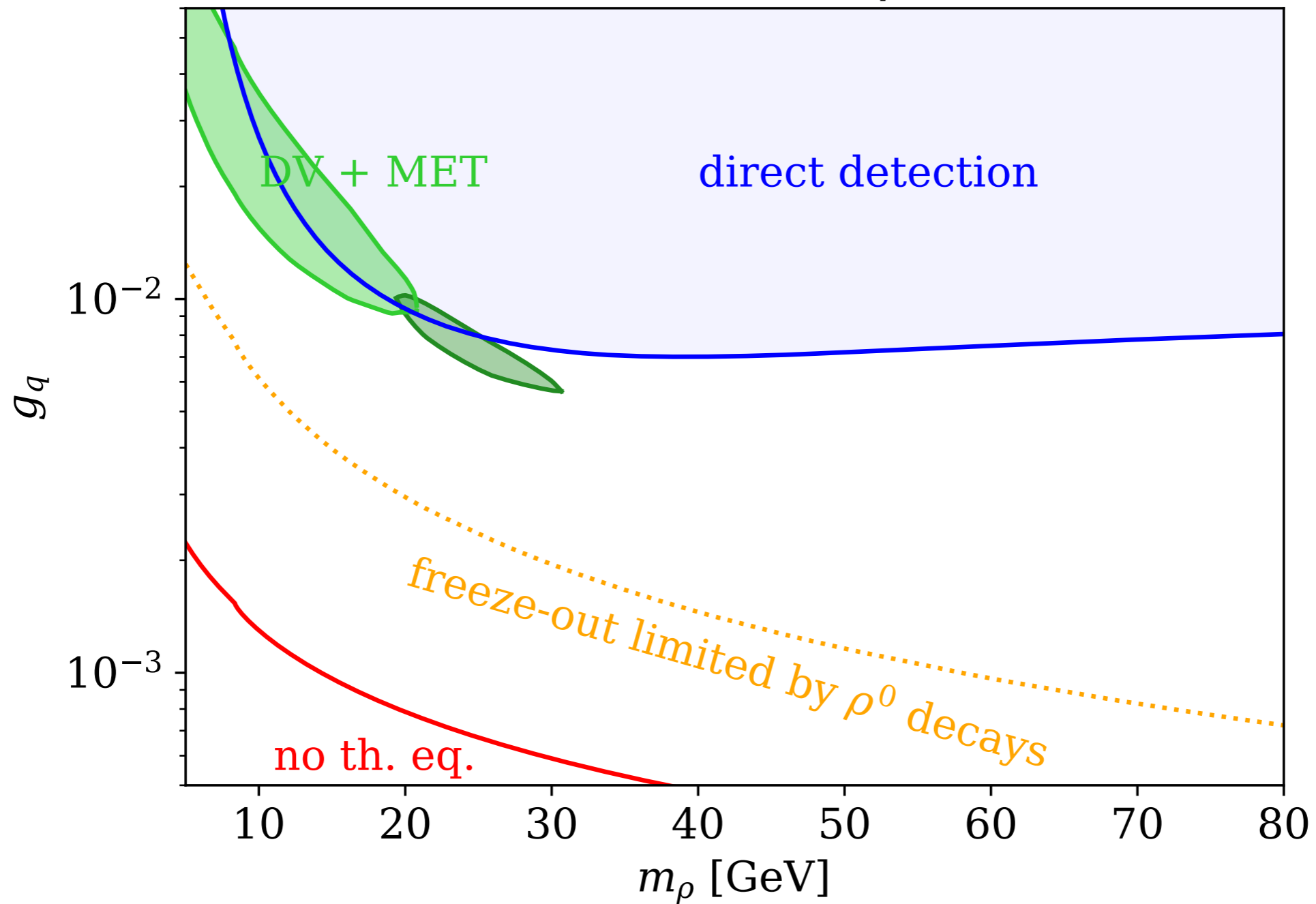


**Existing analysis:**  $m_{\text{DV}} > 10 \text{ GeV}, n_{\text{tracks}} \geq 5$

**Relaxed analysis:**  $m_{\text{DV}} > 3 \text{ GeV}, n_{\text{tracks}} \geq 4$

**Background  $\sim 4$  events**

$$m_{Z'} = 1 \text{ TeV}, e_d = 2g_q, g = 3$$



**Existing analysis:**  $m_{\text{DV}} > 10 \text{ GeV}, n_{\text{tracks}} \geq 5$

**Relaxed analysis:**  $m_{\text{DV}} > 3 \text{ GeV}, n_{\text{tracks}} \geq 4$

**Background  $\sim 4$  events**