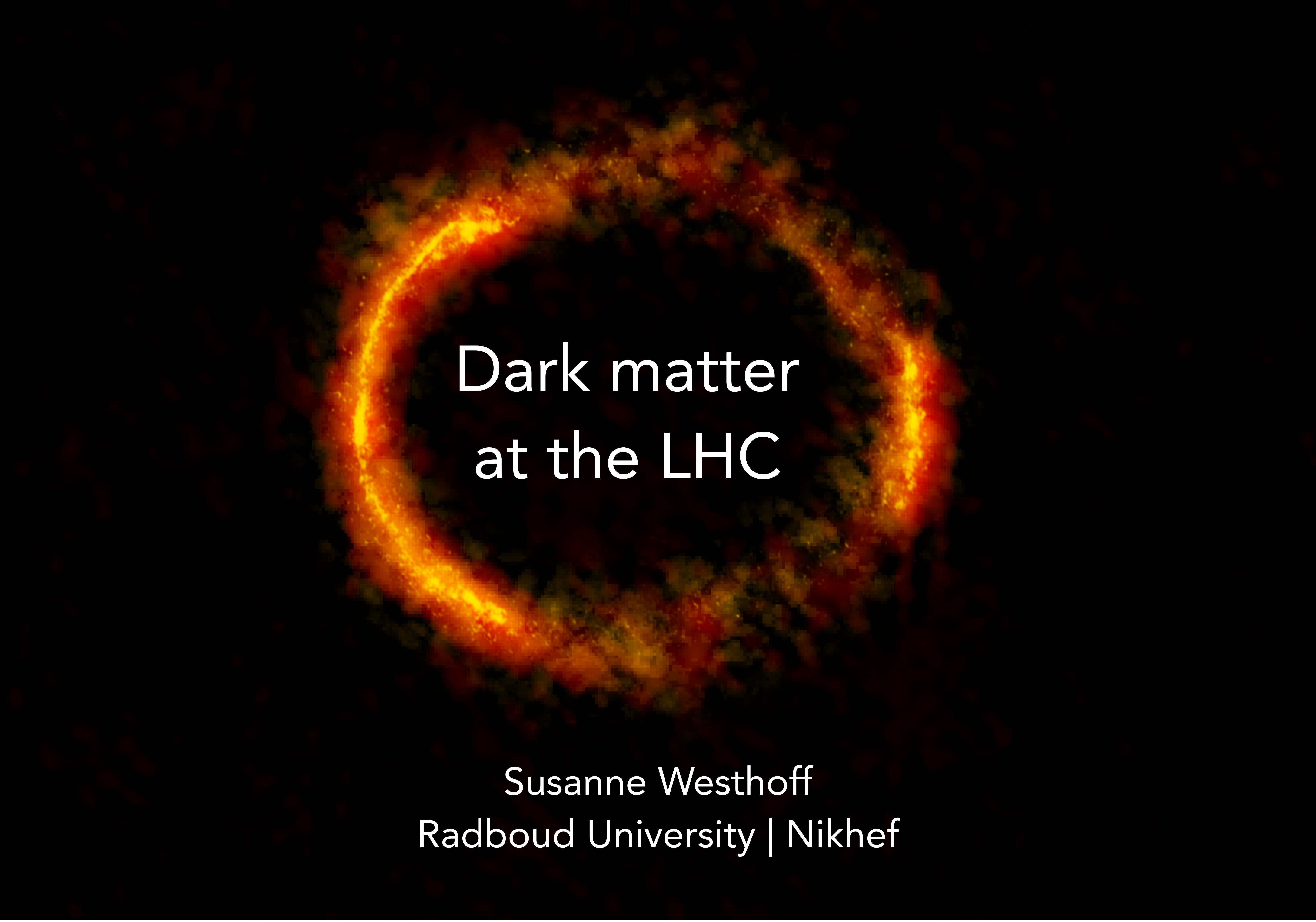
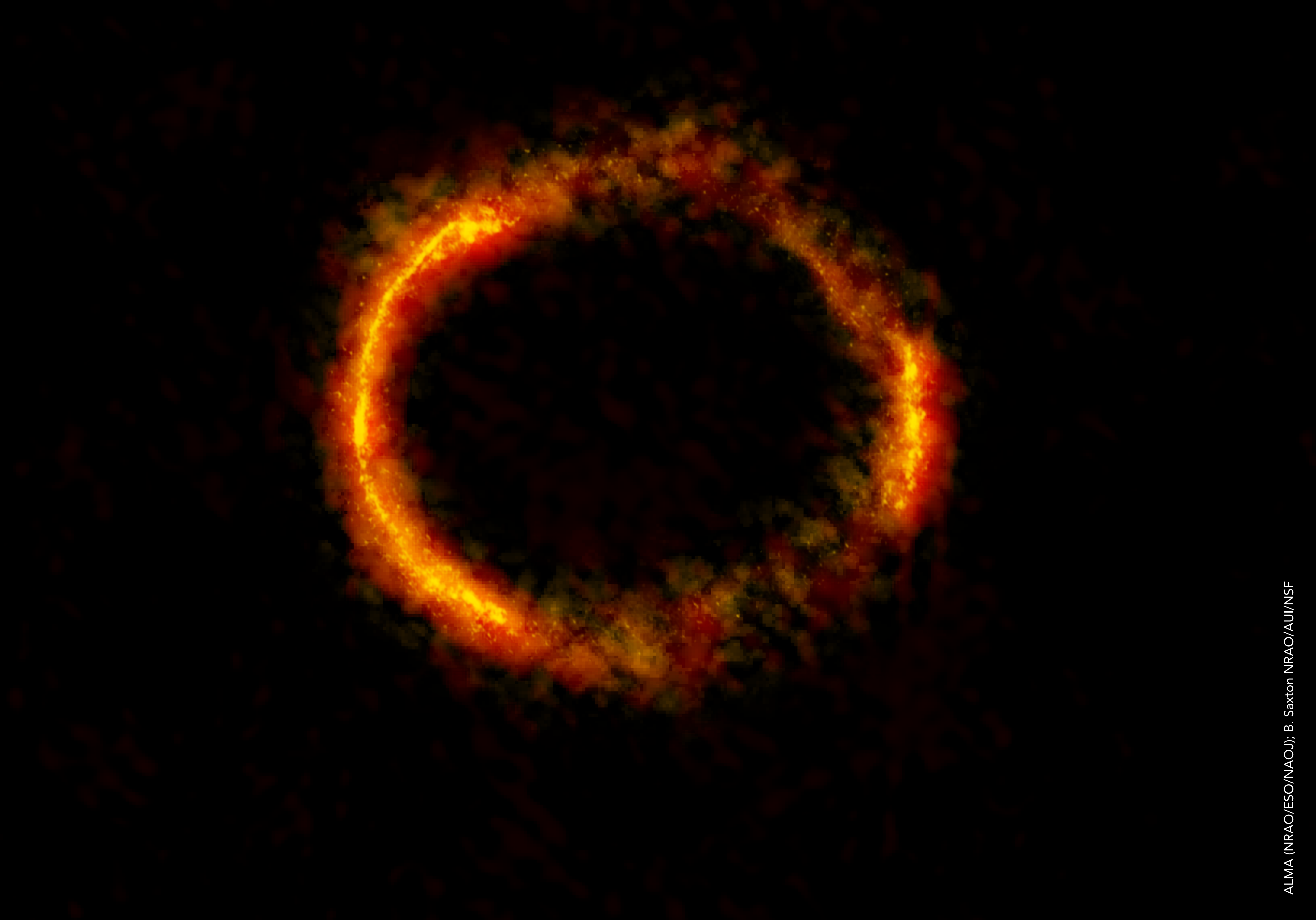


Dark matter at the LHC

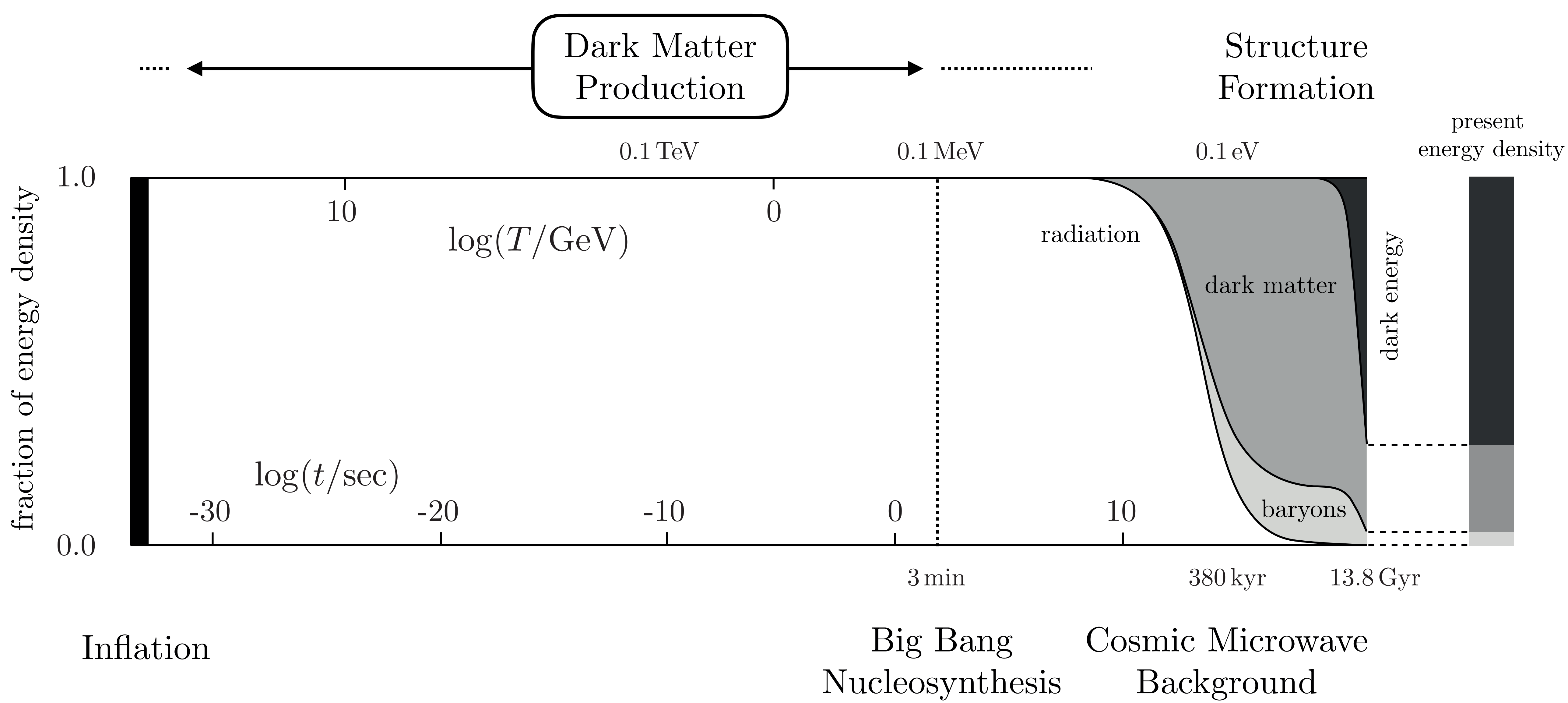
Susanne Westhoff
Radboud University | Nikhef

LHCP | May 25, 2023 | Belgrade



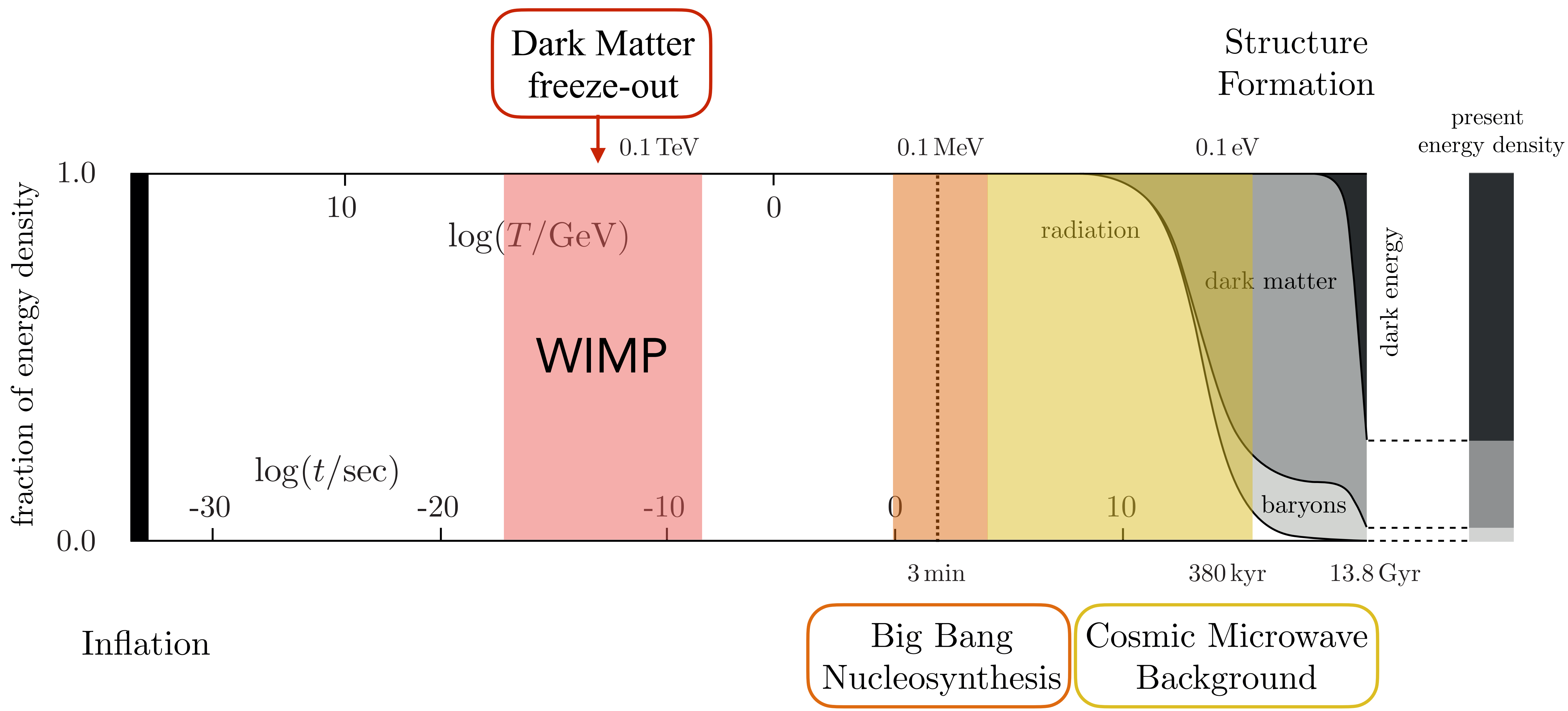
gravitational lensing of galaxy SDP.81, observed by the Atacama Large (sub)Millimeter Array (ALMA)

A bit of history

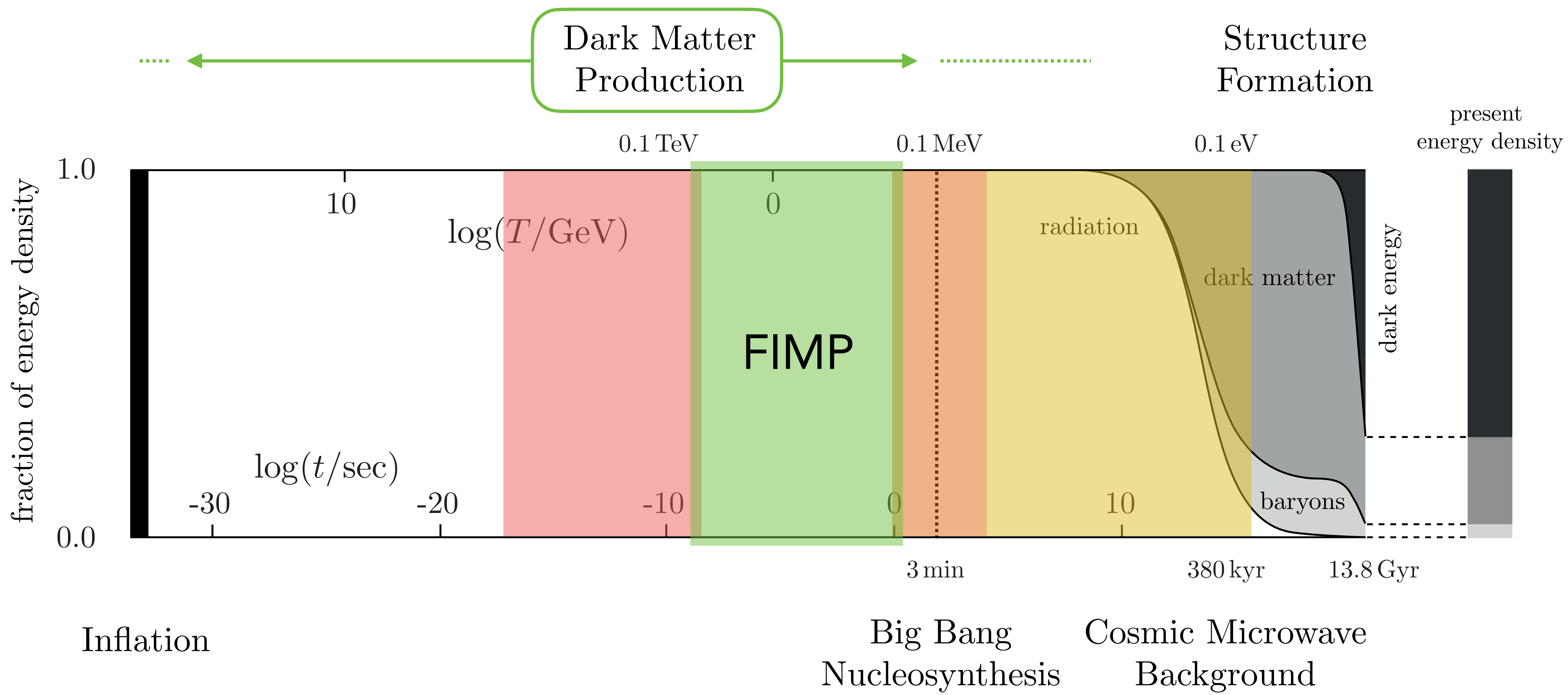


picture: Daniel Baumann's lecture notes

A bit of history

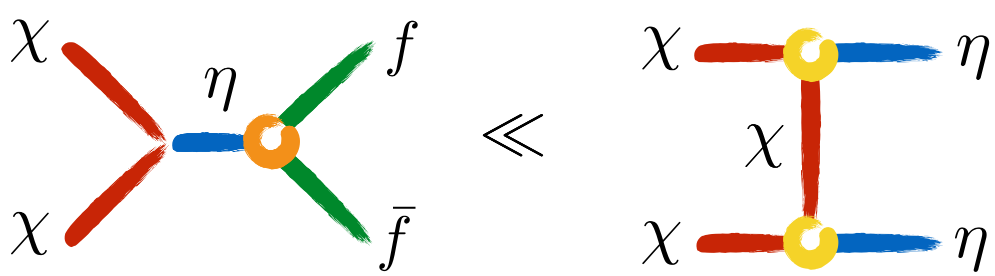


FIMP, the new WIMP



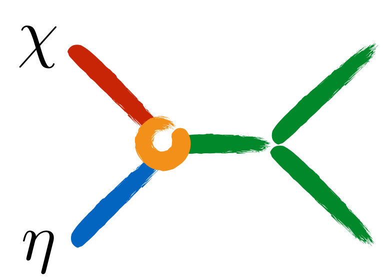
Cosmic history of a FIMP

- Freeze-out into partners: „secluded“ Pospelov et al. 2007



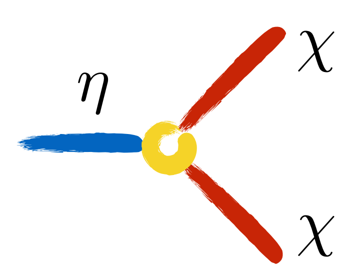
$$\boxed{g_f \ll 1}$$

- Co-annihilation Griest, Seckel 1991



$$\boxed{\frac{m_\eta - m_\chi}{m_\chi} \ll 1}$$

- Freeze-in Hall et al. 2009

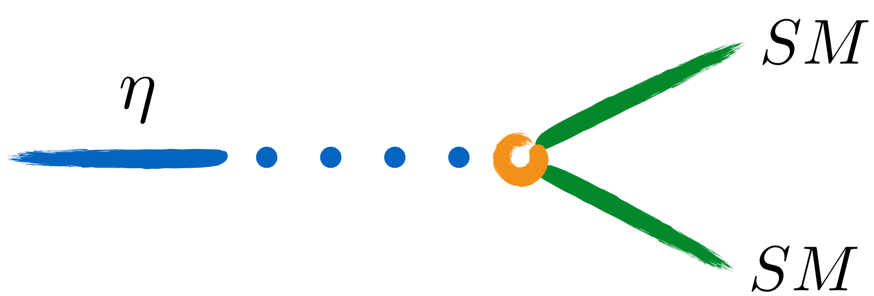


$$\boxed{g_{\chi,f} \ll 1}$$

Long-lived dark partners

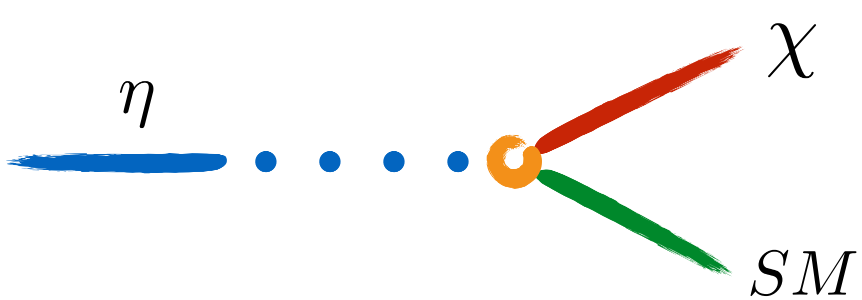
lifetime

- Freeze-out into partners



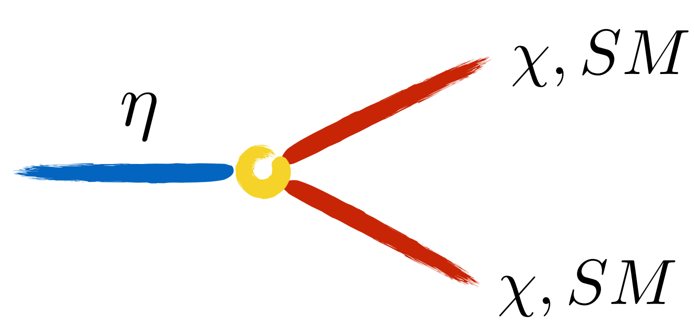
$$\tau_\eta \sim \frac{1}{m_\eta}\frac{1}{g_f^2}$$

- Co-annihilation



$$\tau_\eta \sim \frac{1}{m_\eta}\left(\frac{m_\eta}{m_\eta - m_\chi}\right)^n$$

- Freeze-in



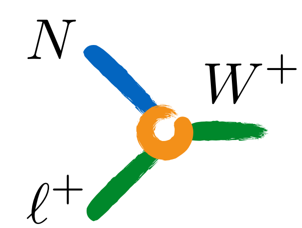
$$\tau_\eta \sim \frac{1}{m_\eta}\frac{1}{g_{\chi,f}^2}$$

Portals to a dark sector

couple one new particle without touching SM symmetries

Neutrino portal: $\mathcal{L} = y_N(\overline{L}H)N + h.c.$

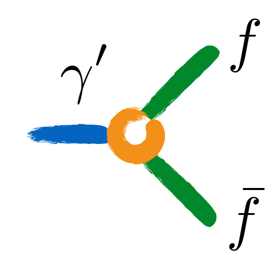
,sterile neutrino‘



$\sim \theta_{\nu N}$

Vector portal: $\mathcal{L} = \epsilon\, F^{\mu\nu} F'_{\mu\nu}$

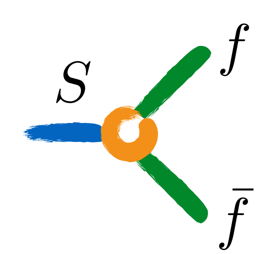
,dark photon‘



$\sim \epsilon e$

Higgs portal: $\mathcal{L} = \lambda_S(H^\dagger H)S$

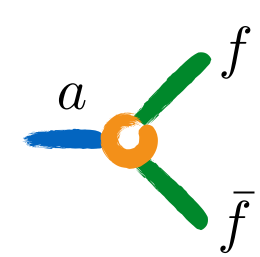
,dark scalar‘



$\sim \frac{m_f}{v}$

Axion portal: $\mathcal{L}_{\text{eff}} = \frac{c_{ff}}{2}\frac{\partial^\mu a}{f_a}(\bar{f}\gamma_\mu\gamma_5 f)$

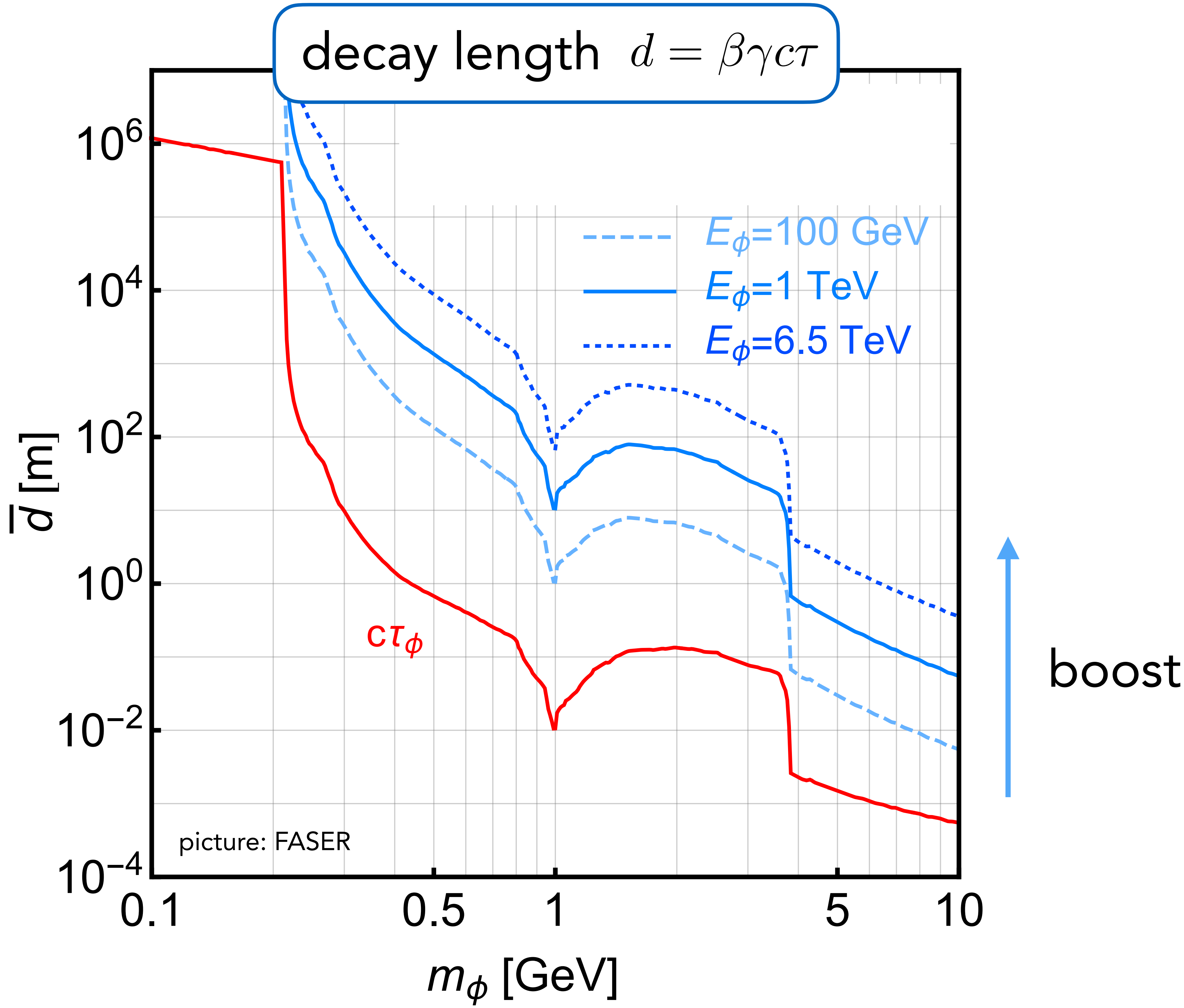
,ALP‘



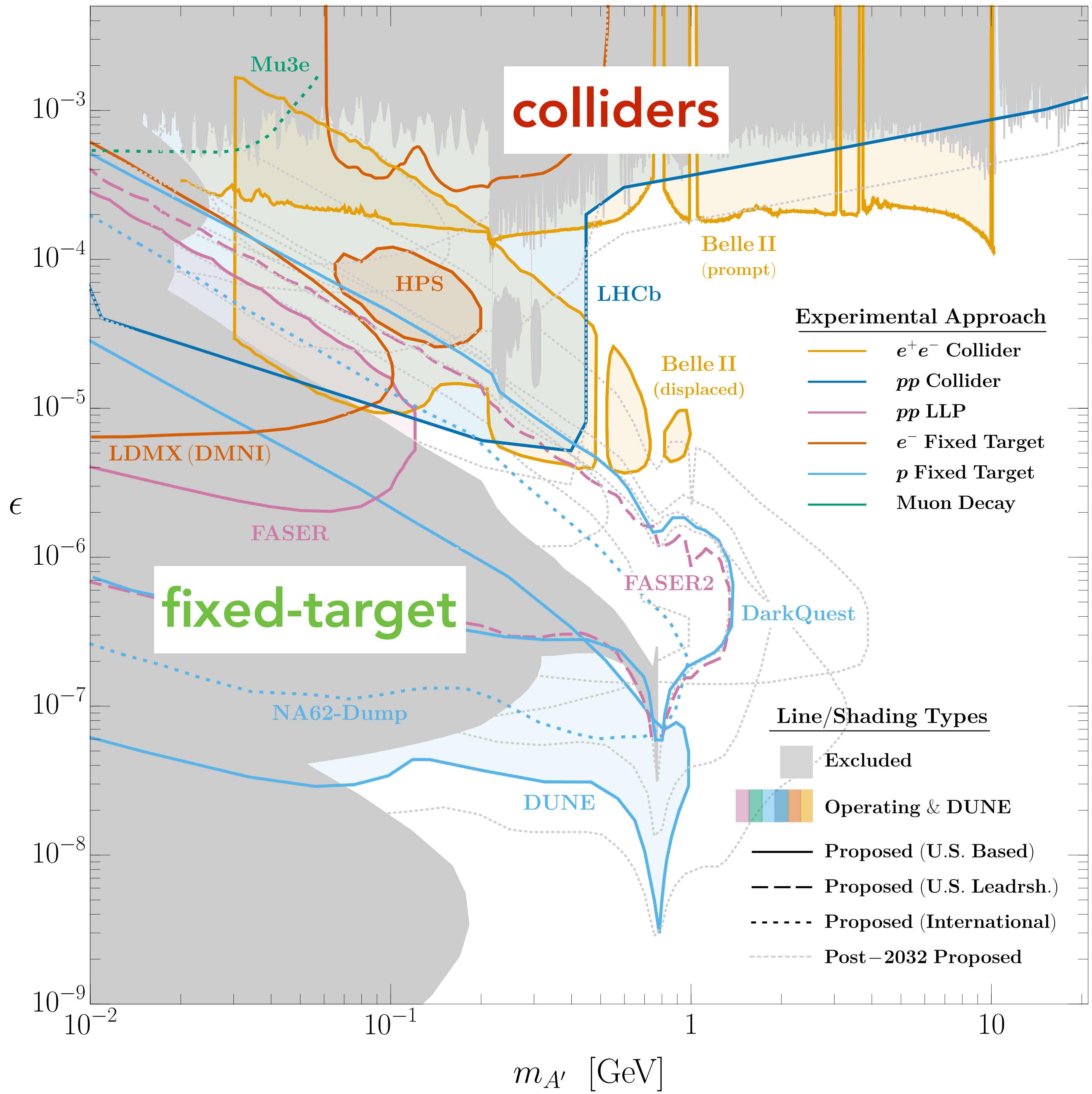
$\sim \frac{m_f}{f_a}$

Pospelov, Ritz, Voloshin 2007; Georgi, Kaplan, Randall 1986

Long-lived particles at high energies

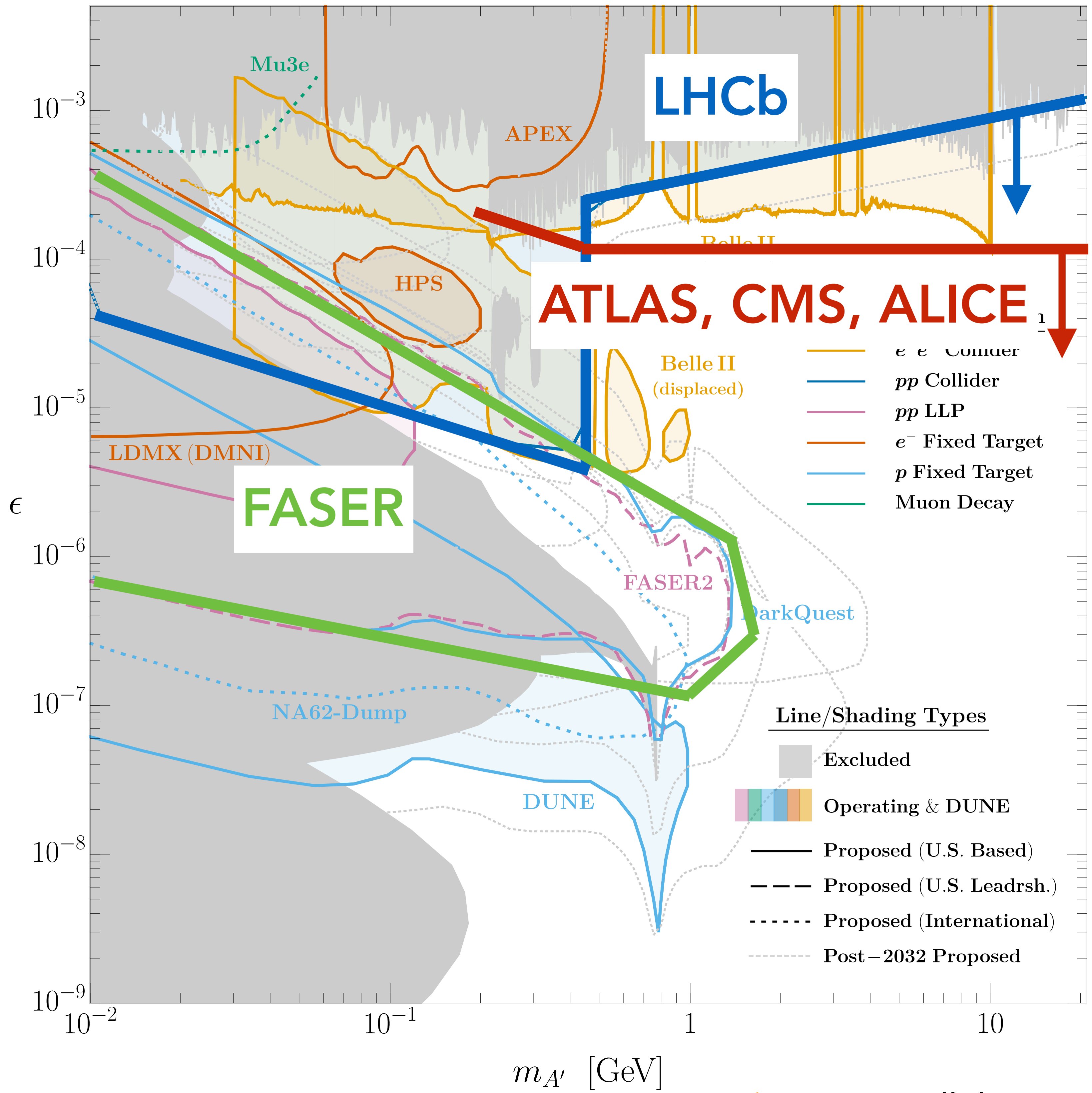


Searches for dark partners



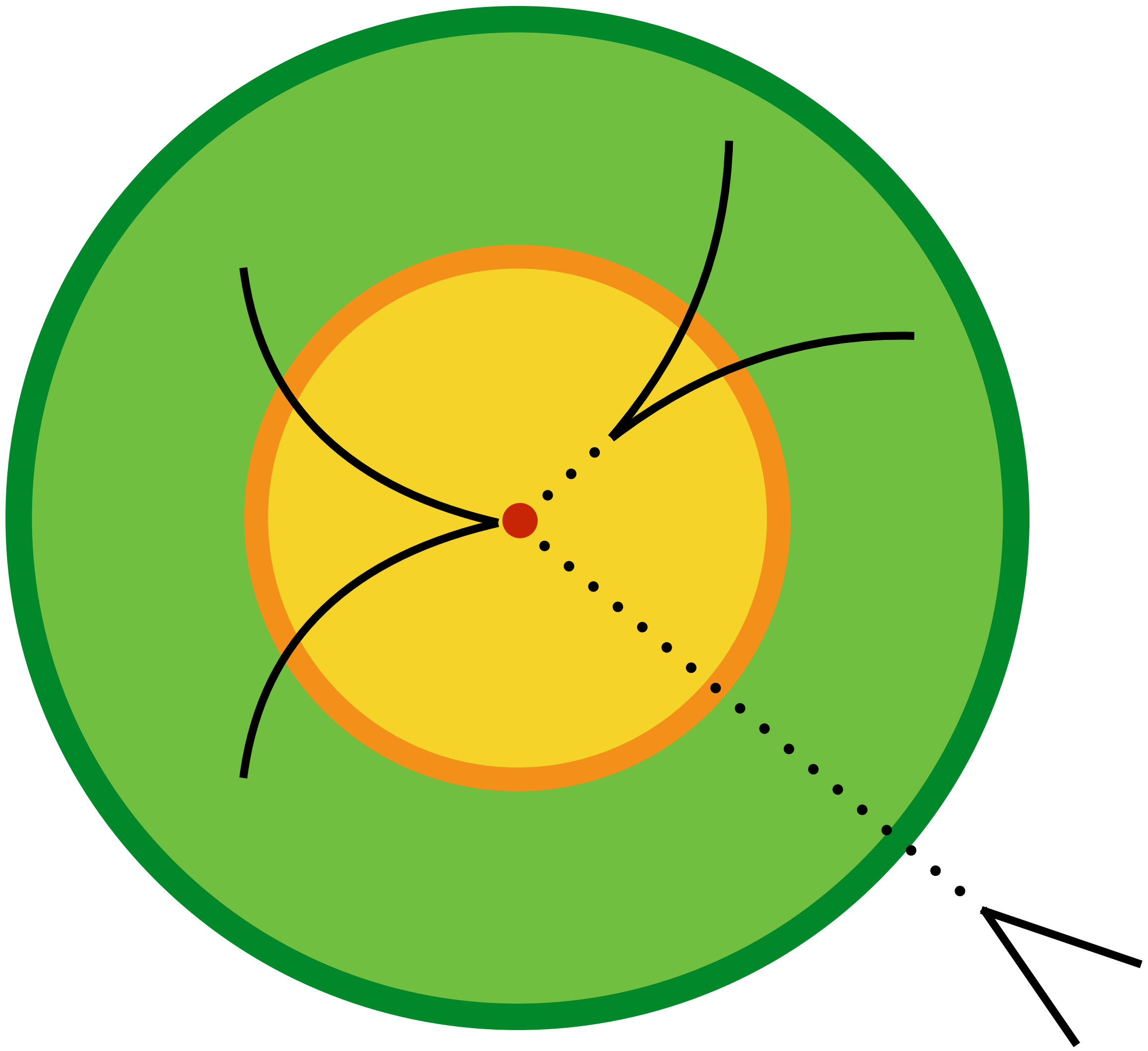
Batell et al. 2207.06905

Role of the LHC



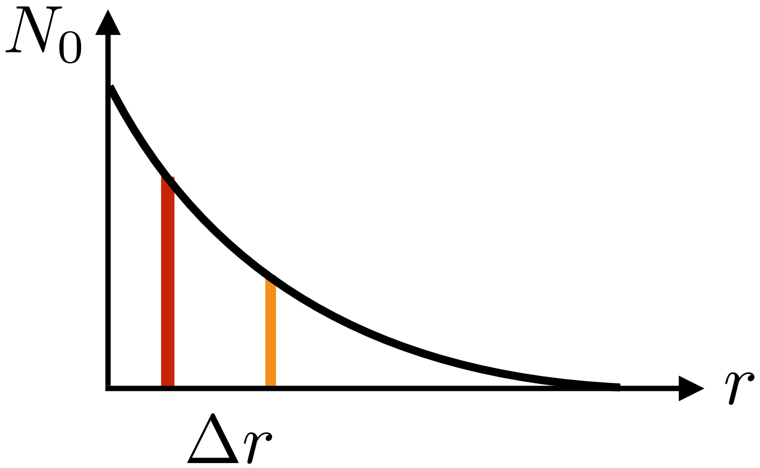
→ LLP parallel sessions on Mon, Tue, Fri

Prompt - displaced - invisible



expected event rate:

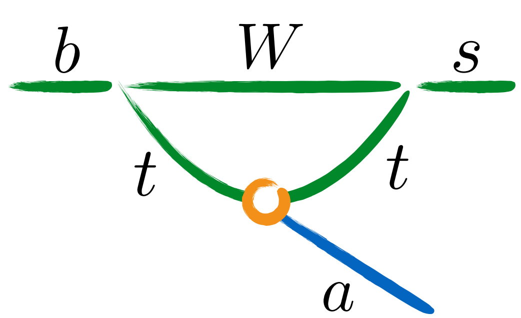
$$N(\Delta V) = N_0 \frac{\Delta\Omega}{4\pi} \left[\exp\left(-\frac{r}{d}\right) - \exp\left(-\frac{r+\Delta r}{d}\right) \right]$$



Axion-like particles

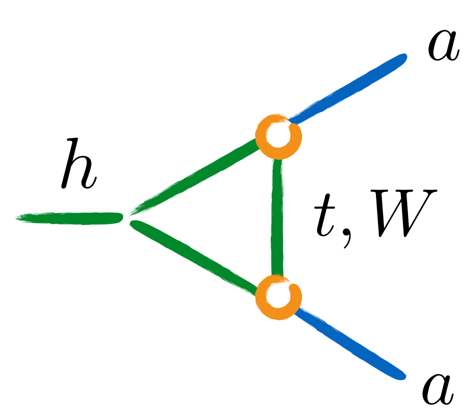
$$\mathcal{L}_{\text{eff}} = -\frac{m_a^2}{2}a^2 + \frac{c_{ff}}{2}\frac{\partial^\mu a}{f_a}(\bar{f}\gamma_\mu\gamma_5 f) + c_{VV}\frac{a}{f_a}V_{\mu\nu}\widetilde{V}^{\mu\nu}$$

LHCb, FASER



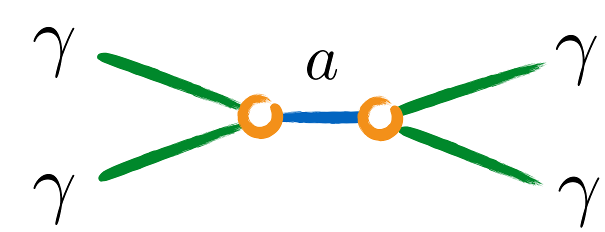
Batell, Pospelov, Ritz
0911.4938

ATLAS, CMS

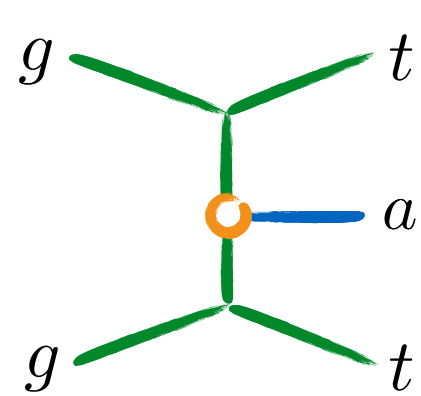


Bauer, Neubert, Thamm
1708.00443

ALICE



d'Enterria et al.
2203.05939



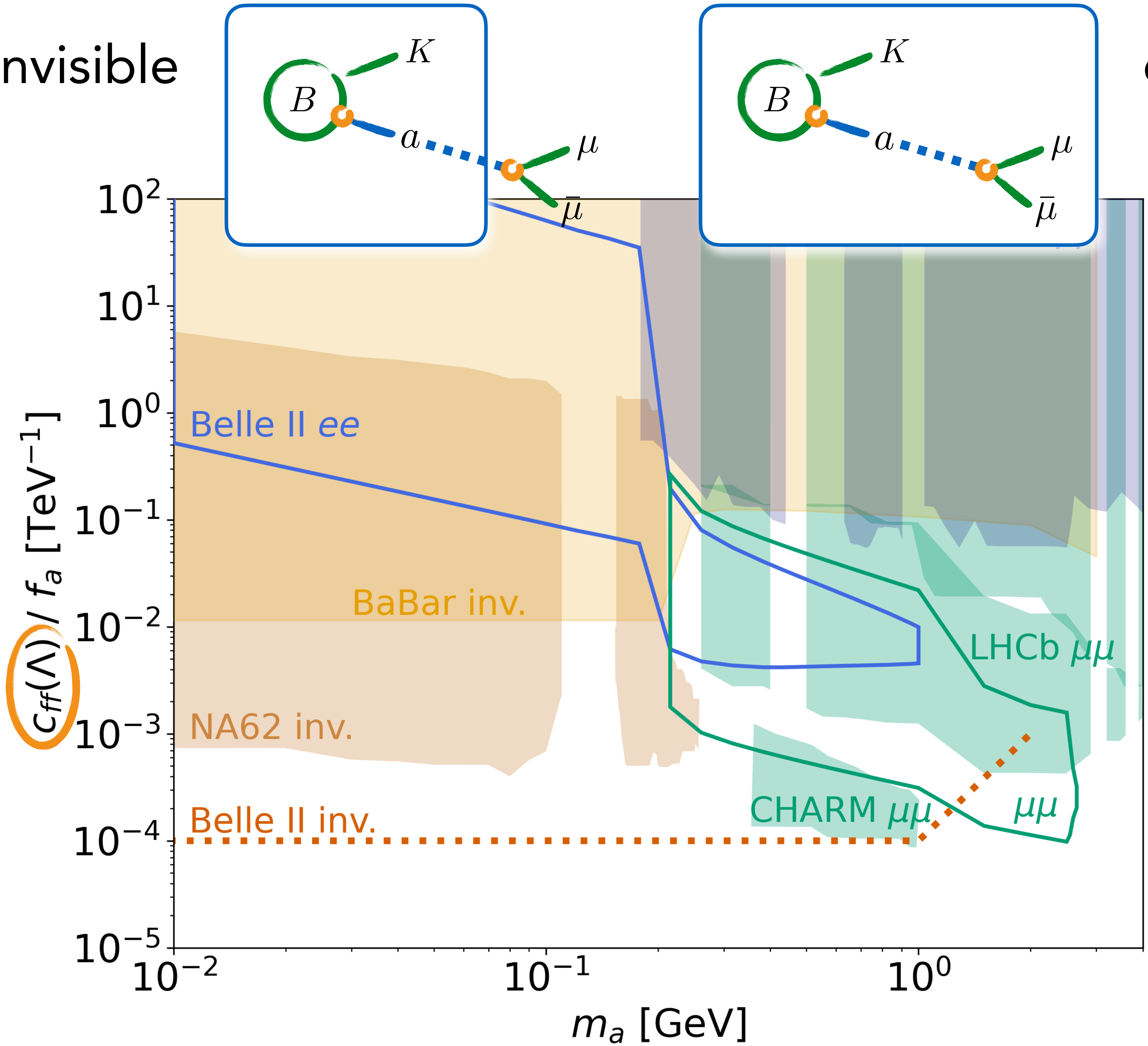
Esser et al. 2303.17634
Rygaard et al. *to appear*

→ talk by Marvin Schnubel (Tue)

LHCb: ALPs from meson decays

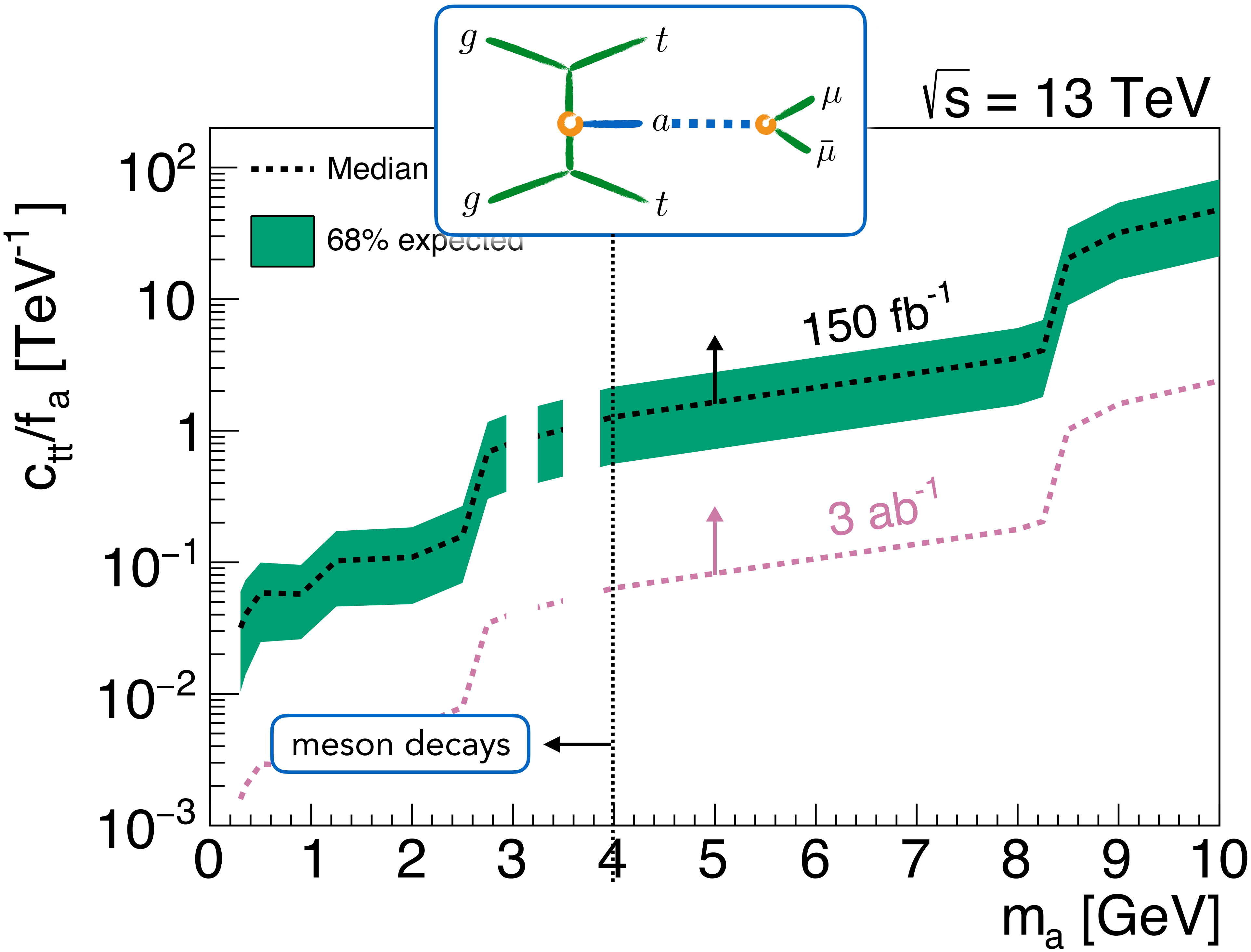
invisible

displaced



Ferber, Filimonova, Schaefer, SW 2201.06580

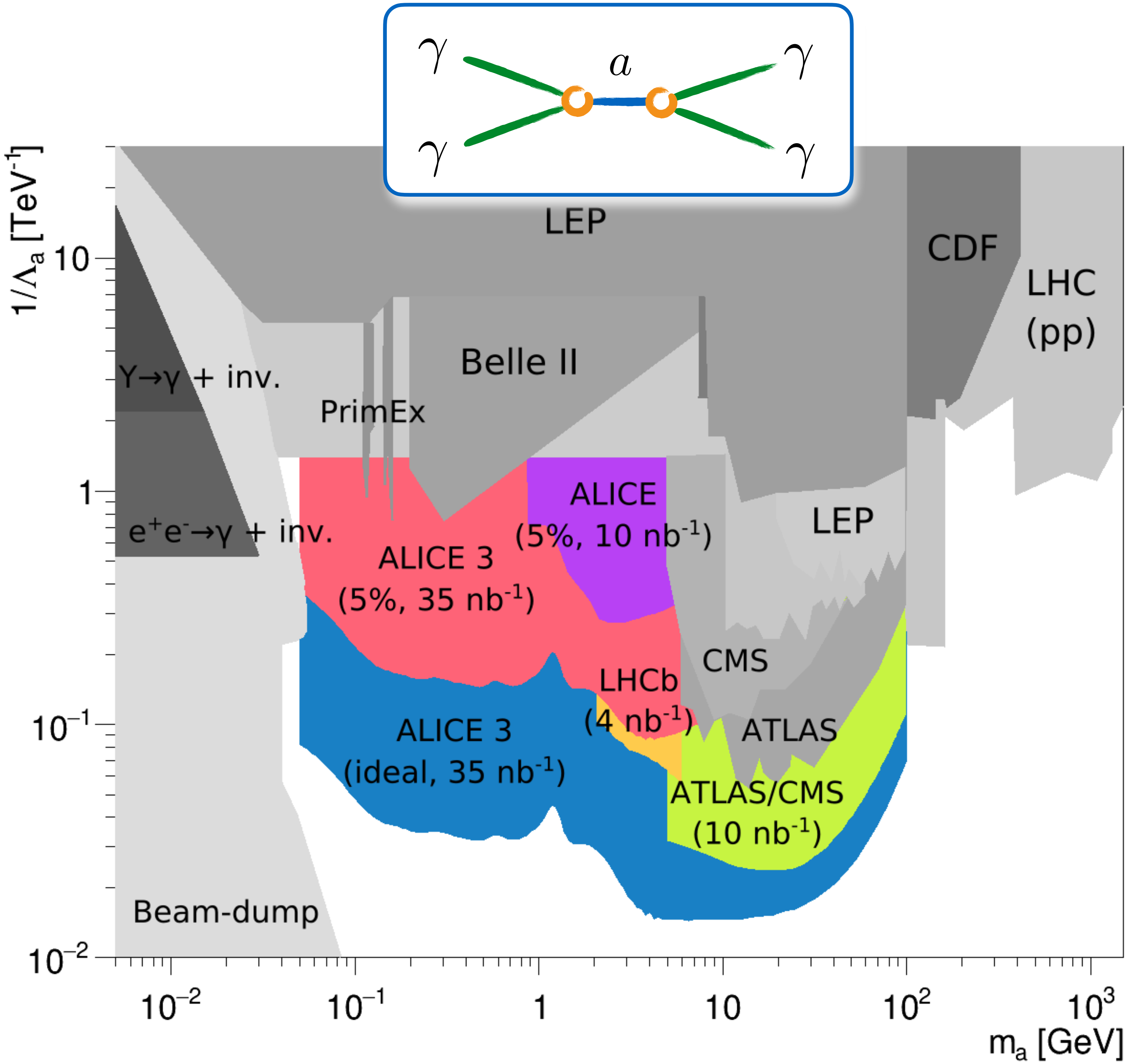
ATLAS, CMS: Displaced ALPs from the top



Rygaard et al.
preliminary

- $pp \to t\bar{t}a,\ a \to \not{E}$: Esser et al. 2303.17634
- $pp \to t\bar{t},\ t \to ca$: Carmona et al. 2202.09371

ALICE: ALPs from photon fusion

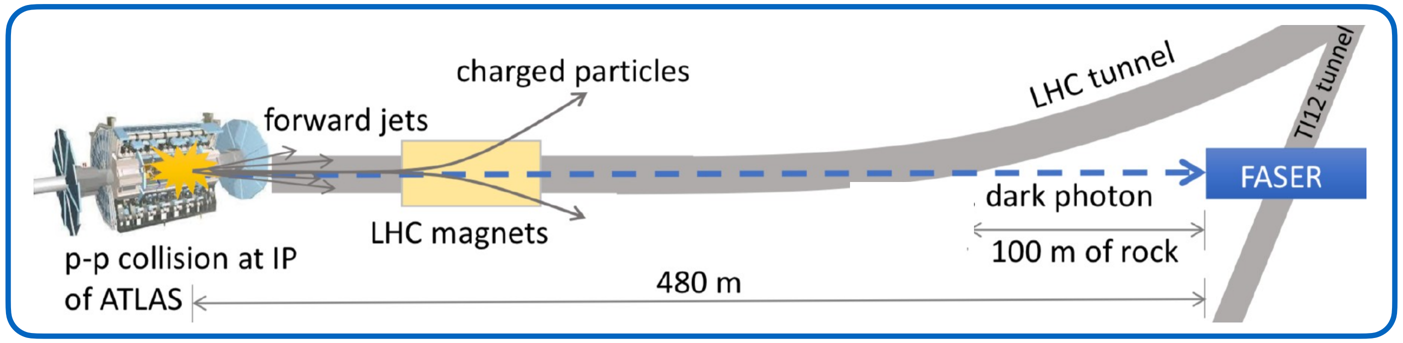


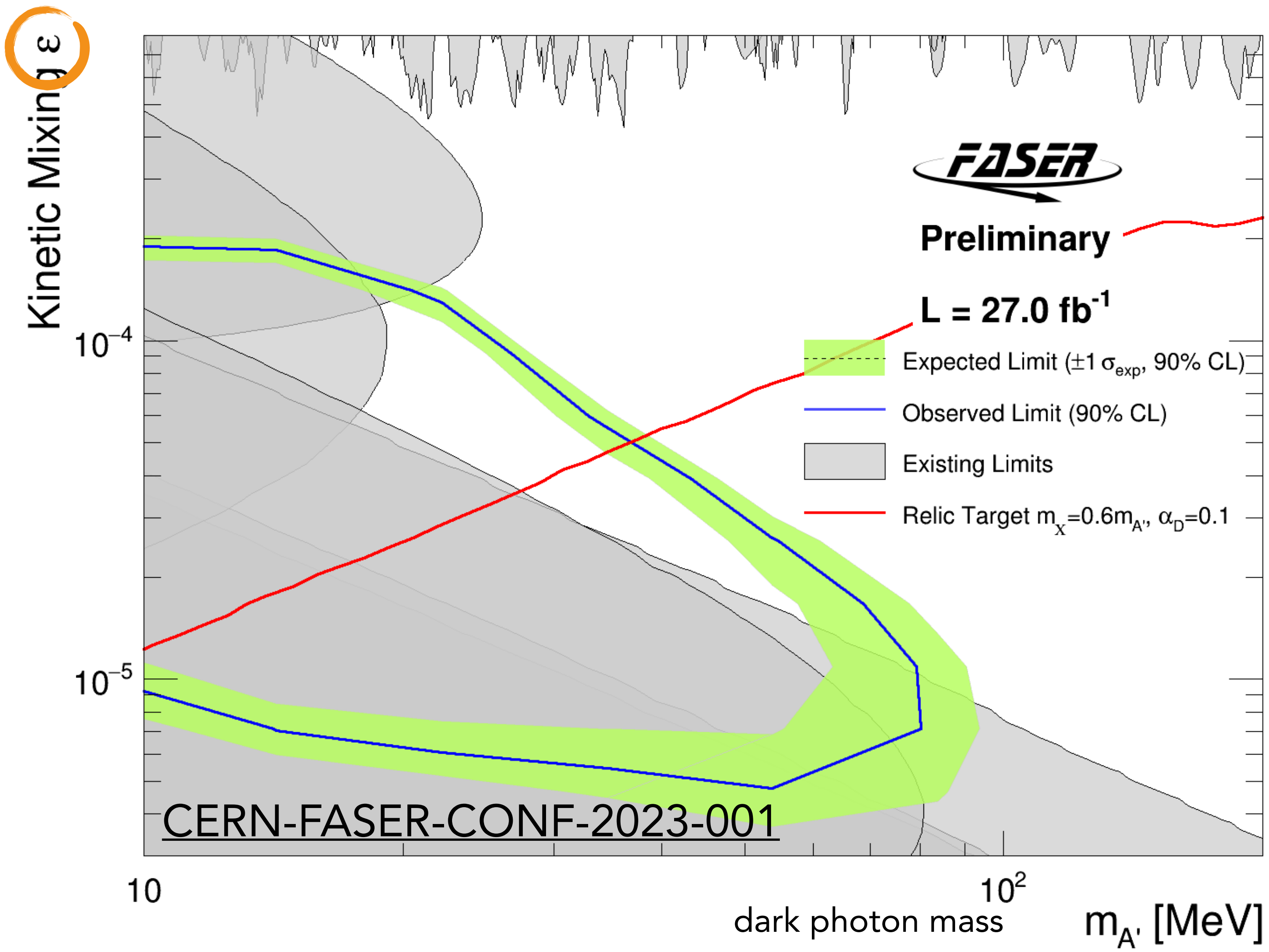
d'Enterria et al.
2203.05939

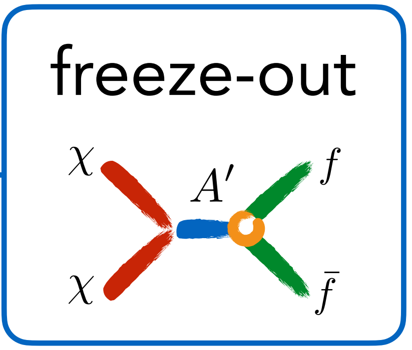
- also ATLAS, CMS (heavy-ion runs) → talk by Davide Zuliani (Tue)

FASER: Ultra-displaced dark photons

→ talk by Noshin Tarannum (Tue)

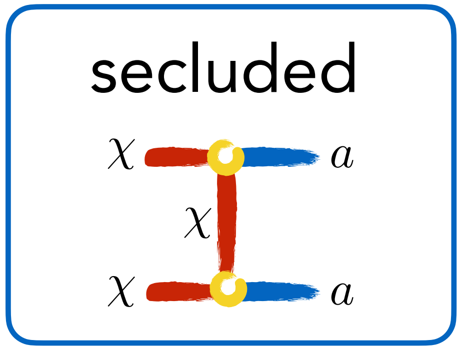


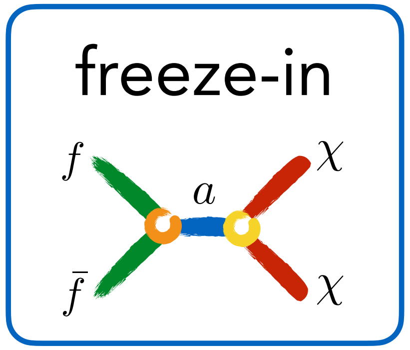


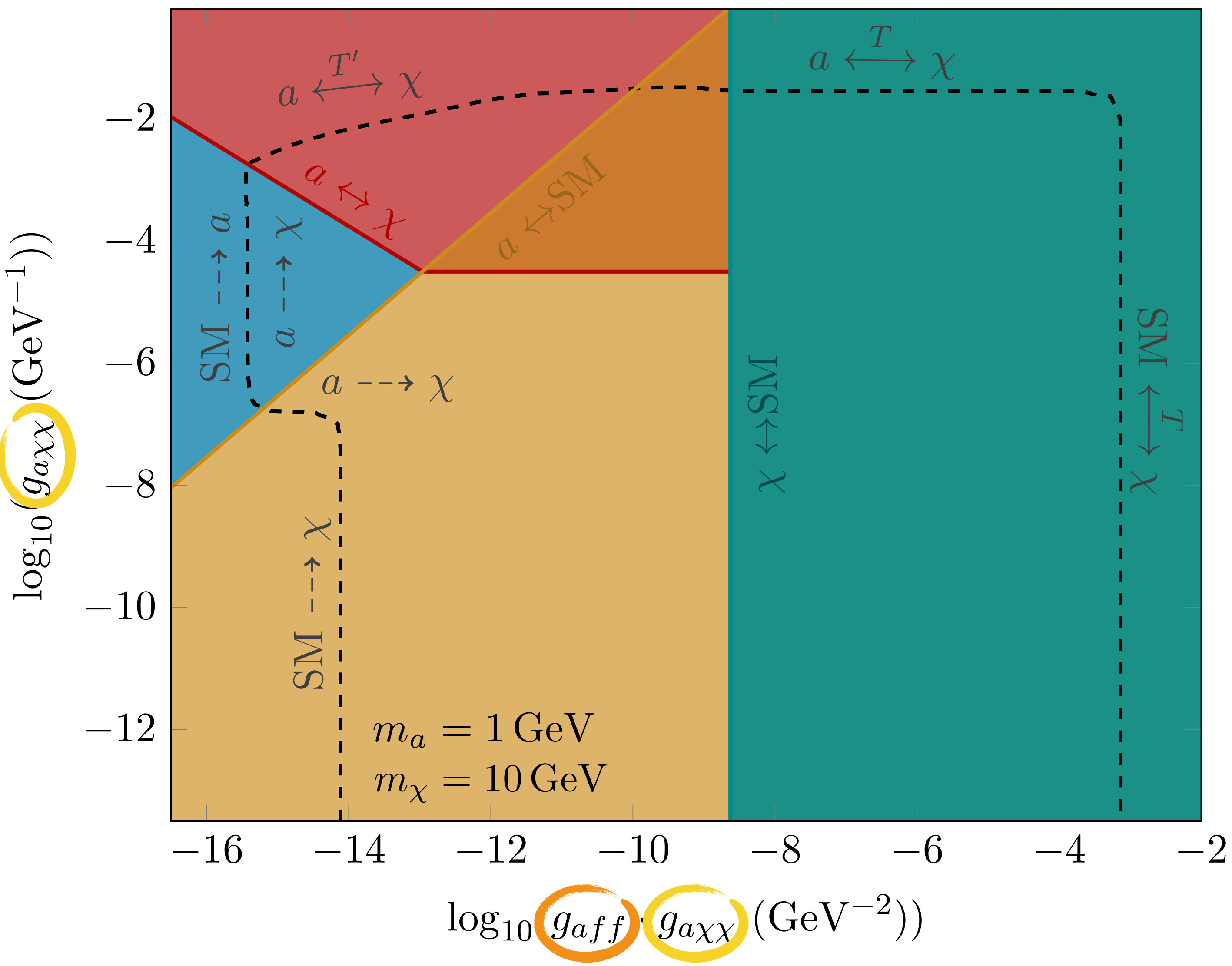


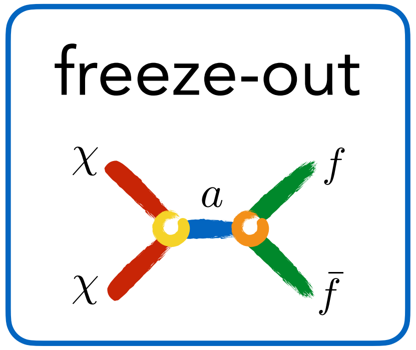
- mono-photons: Dienes et al. 2301.05252

Lessons for dark matter?



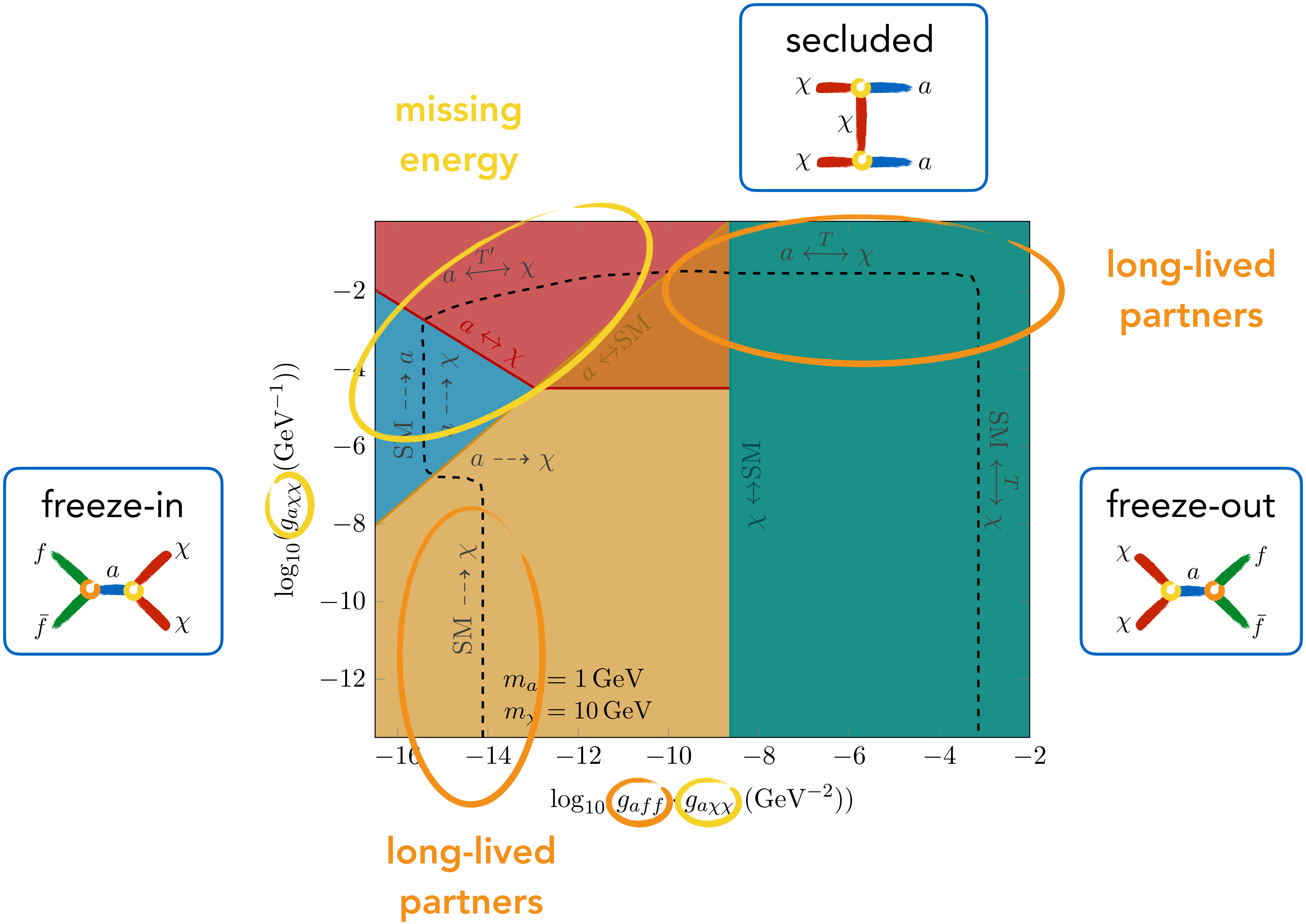




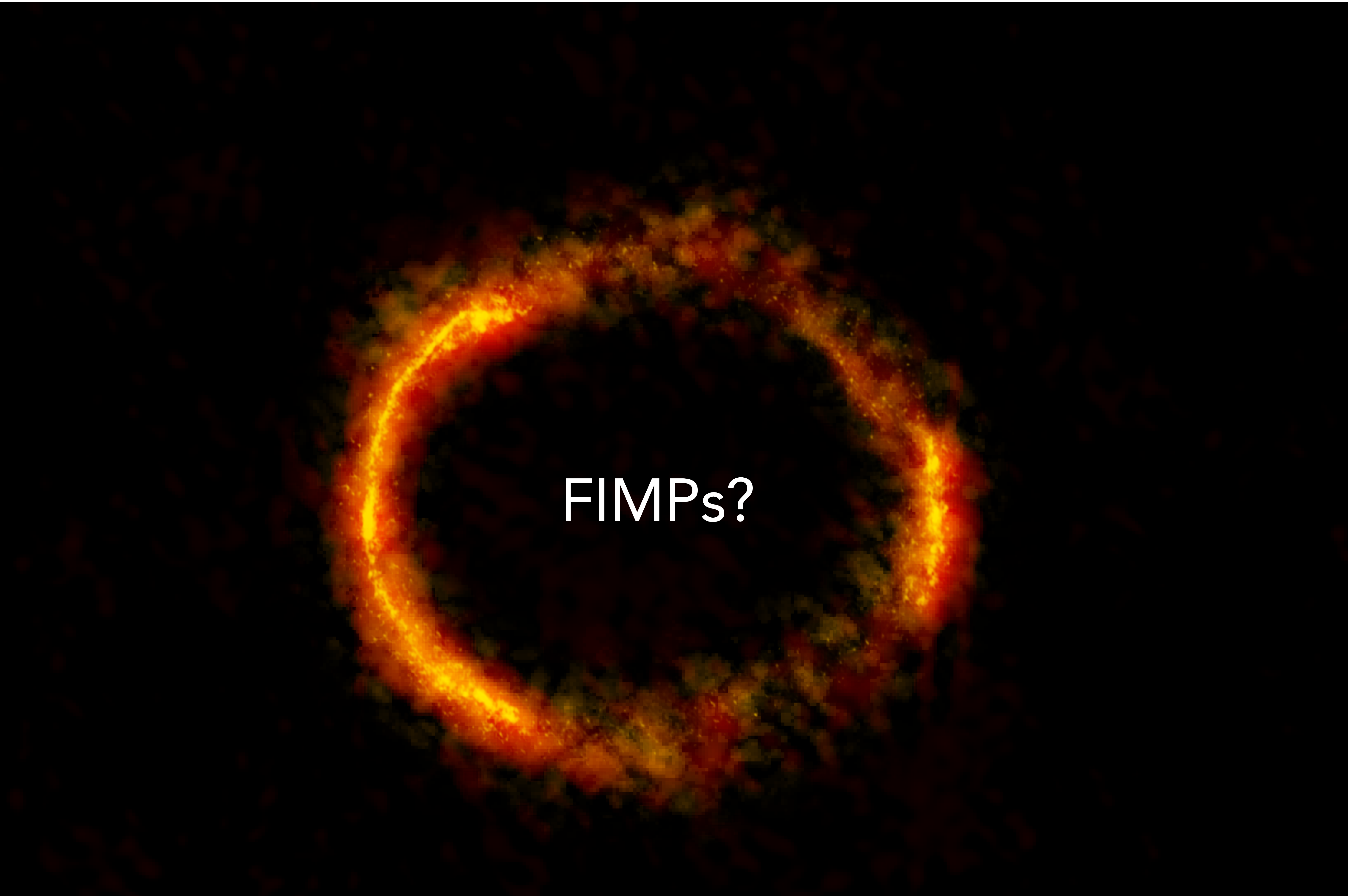


Chu, Hambye, Tytgat 1112.0493; Bharucha et al. 2209.03932

Lessons for dark matter?



Dark Matter at the LHC



Dark Matter beyond the LHC