

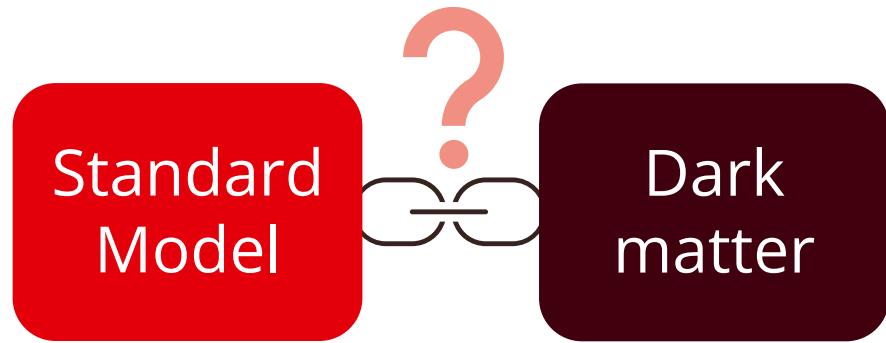
Top of the ALPs

Direct probes of the axion coupling to tops

Anh Vu Phan (Vu), Susanne Westhoff
NNV meeting, Lunteren, 03 Nov 2023

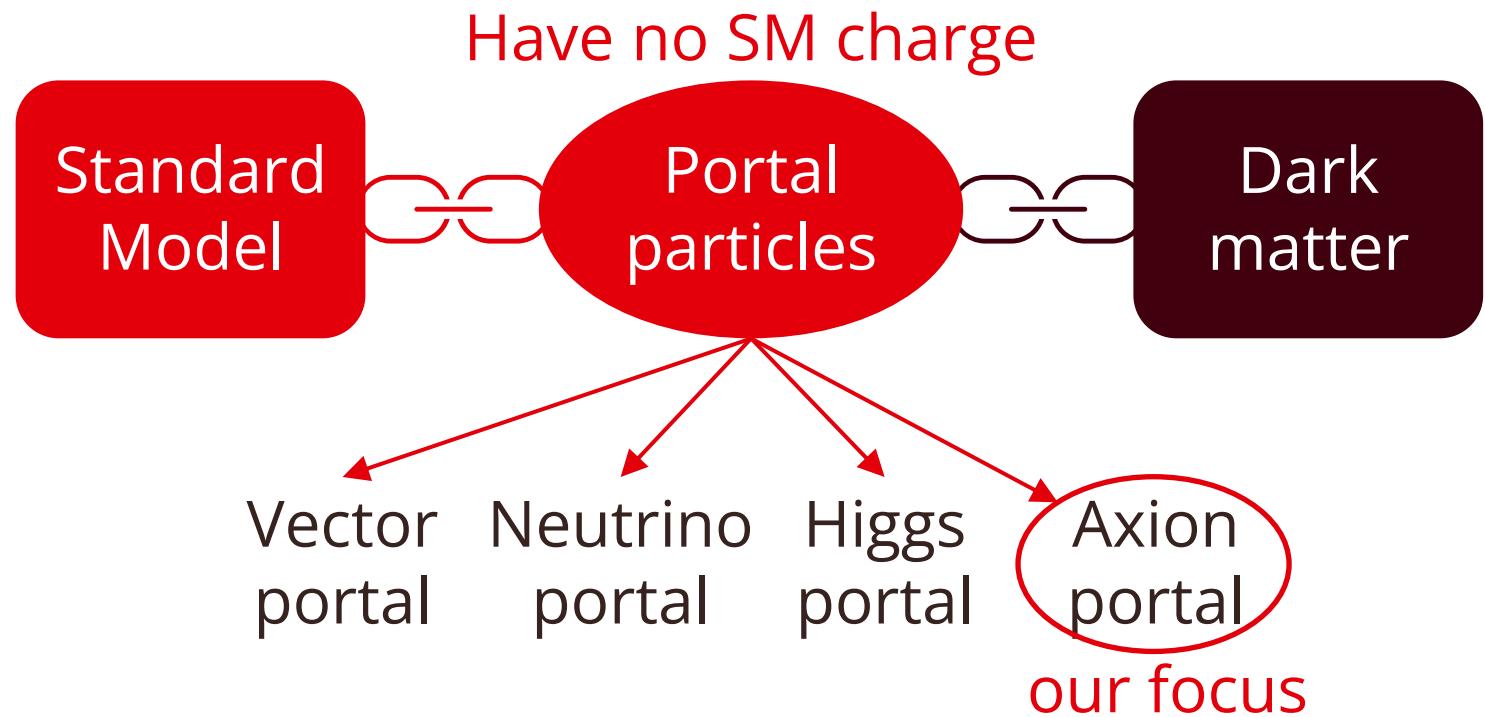
MOTIVATIONS

DARK MATTER



MOTIVATIONS **DARK MATTER**

More on portals to dark sector:
Batell, Pospelov, and Ritz (2009)
Batell, Blinov, Hearty, and McGehee (2022)



MOTIVATIONS

STRONG CP PROBLEM → AXION

$\mathcal{L}_\theta = -\theta_{\text{QCD}} \frac{\alpha_s}{8\pi} G^{A,\mu\nu} \tilde{G}_{\mu\nu}^A$ is allowed ⇒ must include

neutron electric dipole moment $d_n = 5.2 \times 10^{-16} e \cdot \text{cm}$ $\bar{\theta}$

$$\bar{\theta} = \theta_{\text{QCD}} - \arg \det(Y_d Y_u)$$

Abel et al. (2020) ⇒ $|d_n| < 1.8 \times 10^{-26} e \cdot \text{cm} \Rightarrow |\bar{\theta}| < 3.5 \times 10^{-11}$

Strong CP problem: why $\bar{\theta}$ so small?

MOTIVATIONS

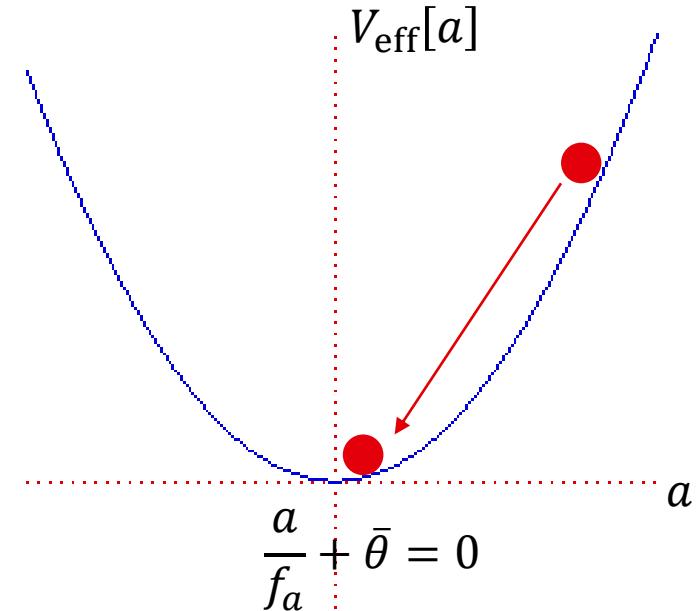
STRONG CP PROBLEM → AXION

Solution: make θ dynamical

$$\begin{aligned} \mathcal{L}_\theta &= -\theta_{\text{QCD}} \frac{\alpha_s}{8\pi} G^{A,\mu\nu} \tilde{G}_{\mu\nu}^A \\ &\quad - \left[\frac{a}{f_a} + \theta_{\text{QCD}} \right] \frac{\alpha_s}{8\pi} G^{A,\mu\nu} \tilde{G}_{\mu\nu}^A \end{aligned}$$

$\Rightarrow a$ naturally relaxes to $d_n \propto \frac{a}{f_a} + \bar{\theta} = 0$

↑
axion
(pseudoscalar)

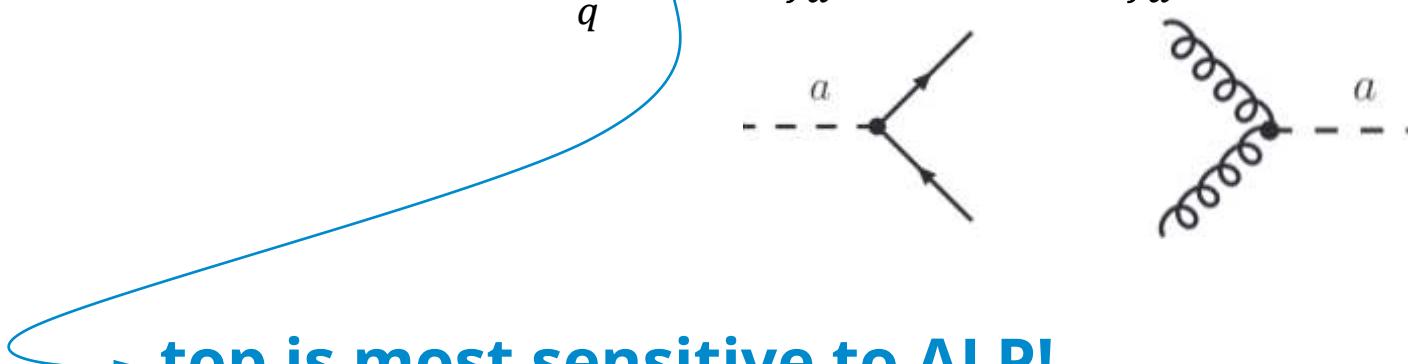


MODEL

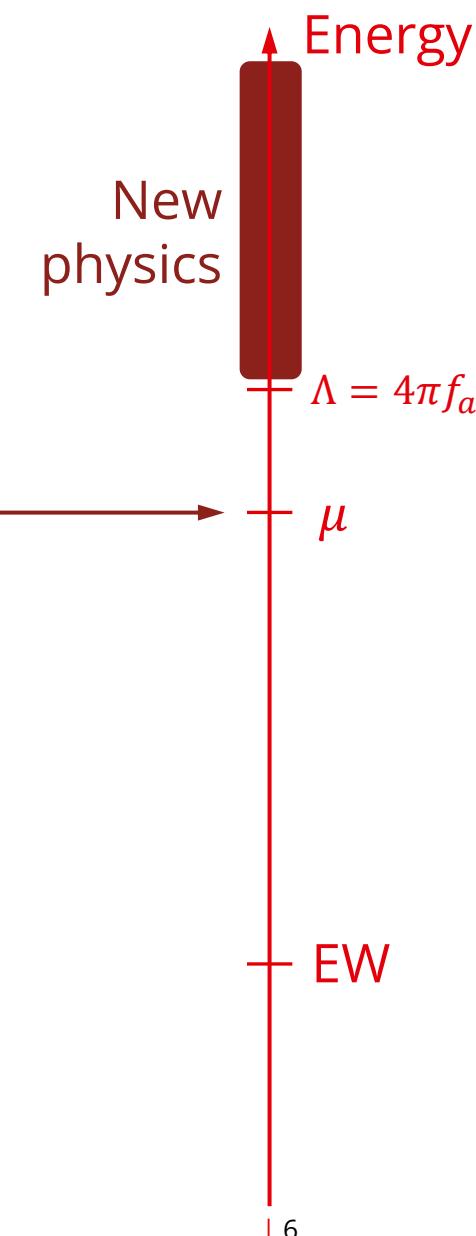
AXION-LIKE PARTICLE (ALP)

- Generalization of the axion (a pseudo-scalar)

$$\mathcal{L}_{\text{eff}}(\mu) \supset \frac{1}{2} \partial_\mu \mathbf{a} \partial^\mu \mathbf{a} - \frac{m_a^2}{2} \mathbf{a}^2 - \sum_q m_q c_{qq} \frac{\mathbf{a}}{f_a} \bar{q} i \gamma^5 q + \tilde{c}_{GG} \frac{\mathbf{a}}{f_a} \frac{\alpha_s}{4\pi} G_{\mu\nu}^A \tilde{G}^{A,\mu\nu}$$



top is most sensitive to ALP!
Goal: study ALP effects on top observables

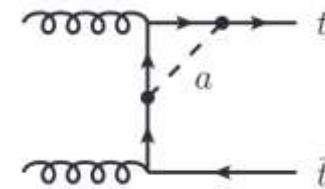
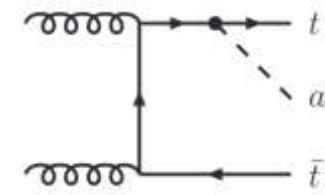
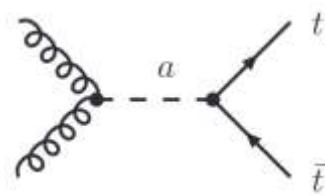


MODEL

AXION-LIKE PARTICLE (ALP)

Leading contributions

Tree-level
Real ALP radiation
Virtual corrections



RESULTS

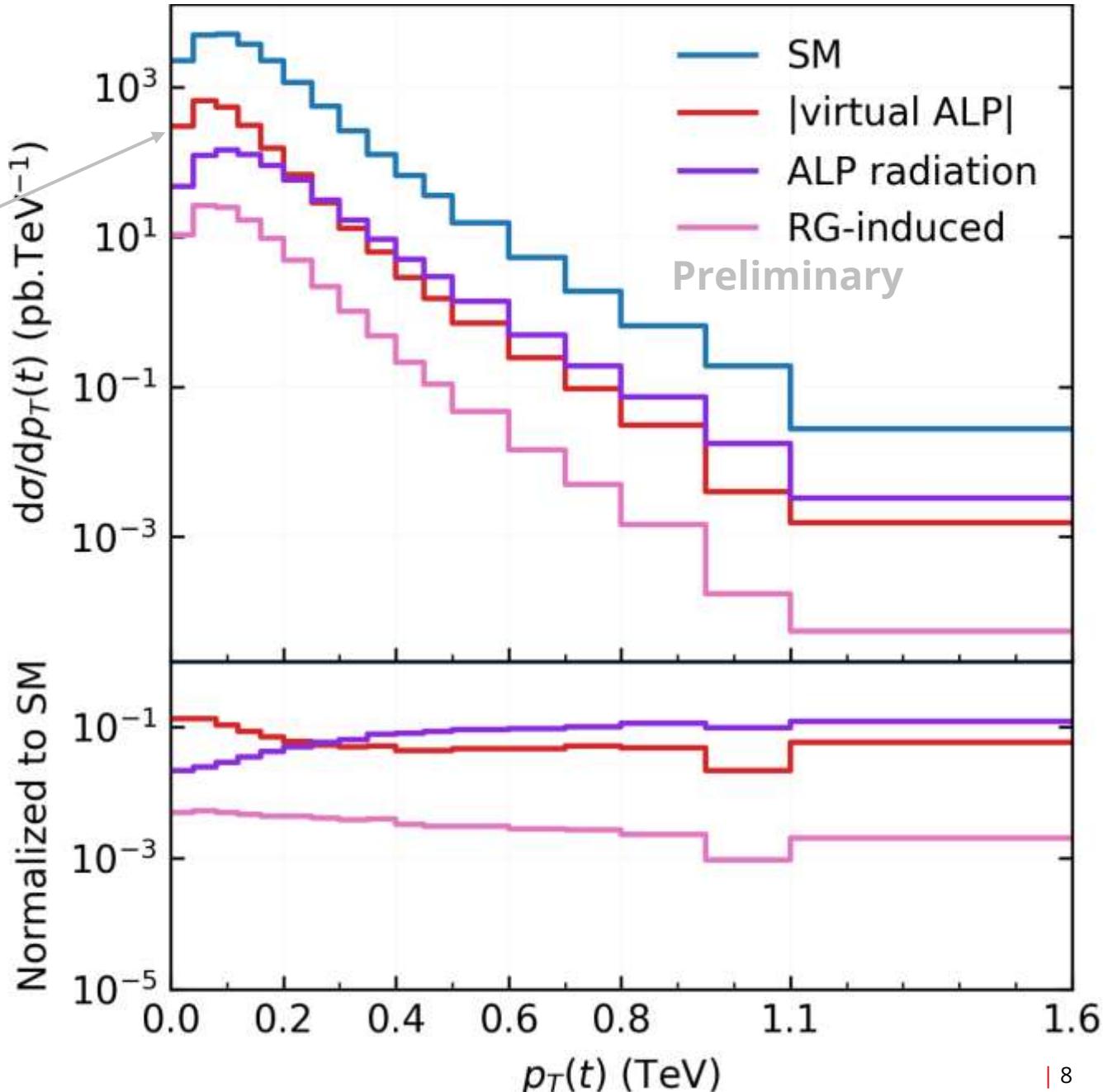
INDIVIDUAL CONTRIBUTIONS

SM: PRD 104 (2021) 092013

Virtual ALP contribution
is negative

$$\frac{c_{tt}(\Lambda)}{f_a} = 20 \text{ TeV}^{-1}; \tilde{c}_{GG}(\Lambda) = 0; m_a = 10 \text{ GeV}$$

New Physics scale $\Lambda = 4\pi f_a$



RESULTS

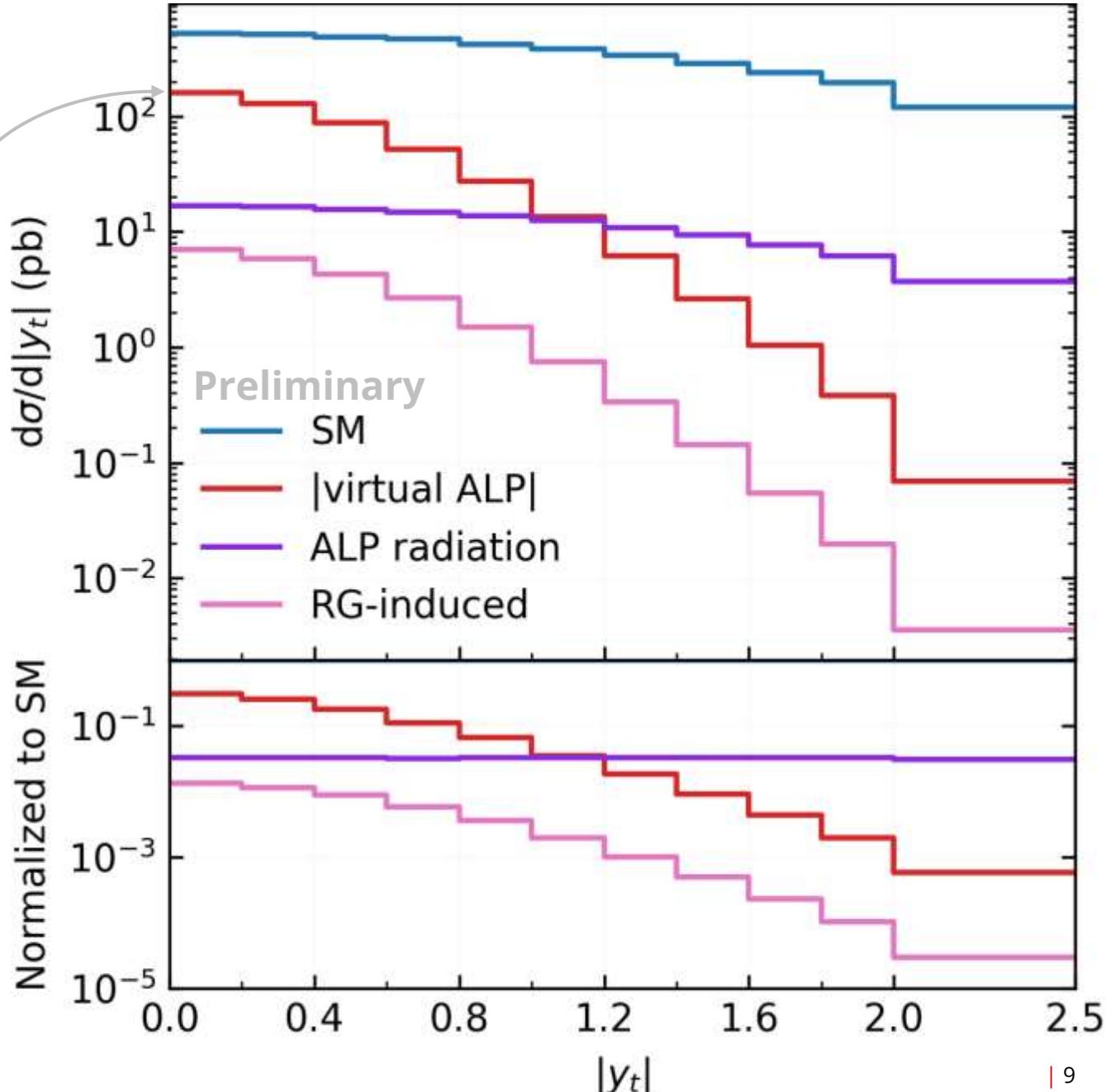
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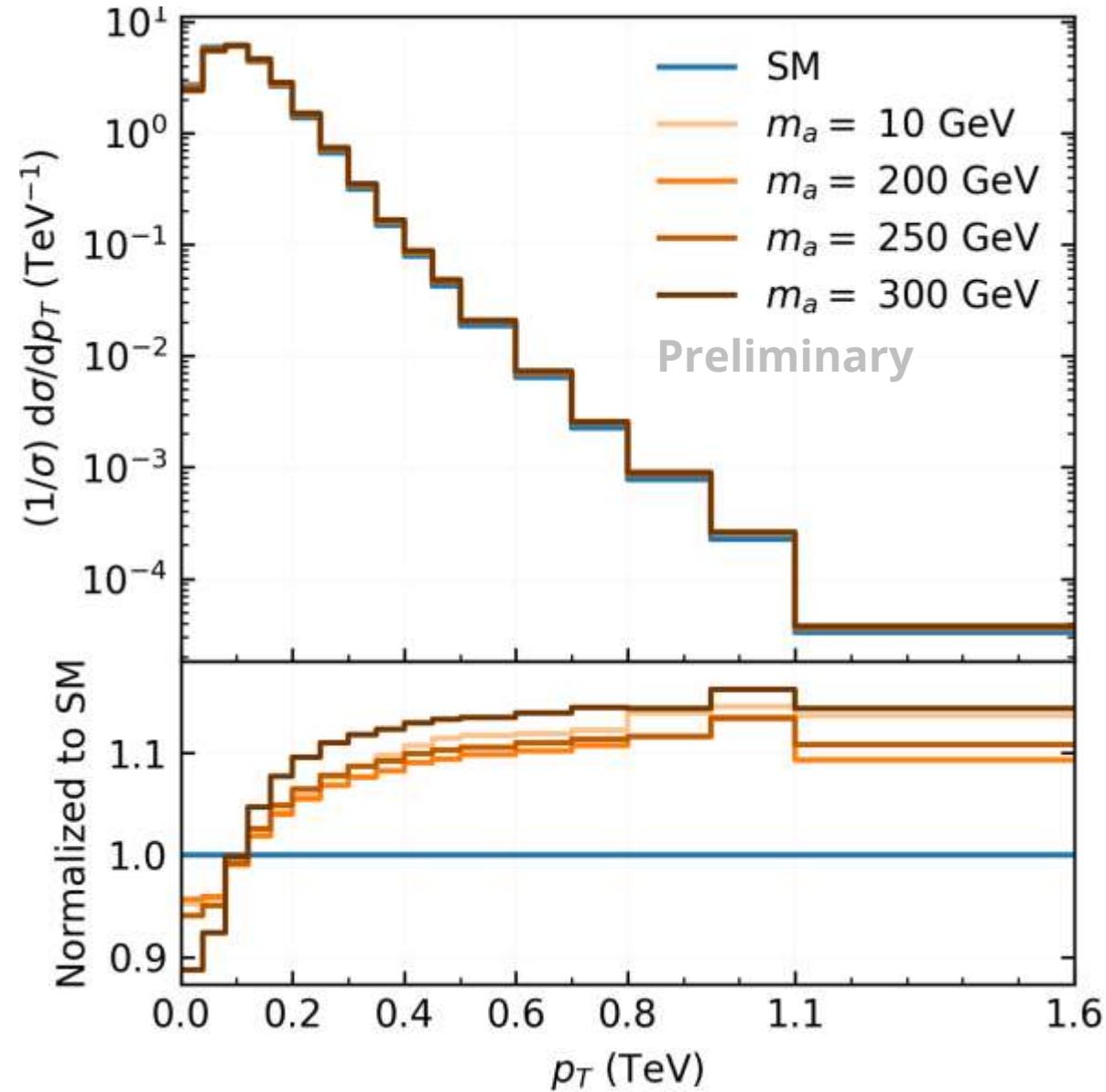
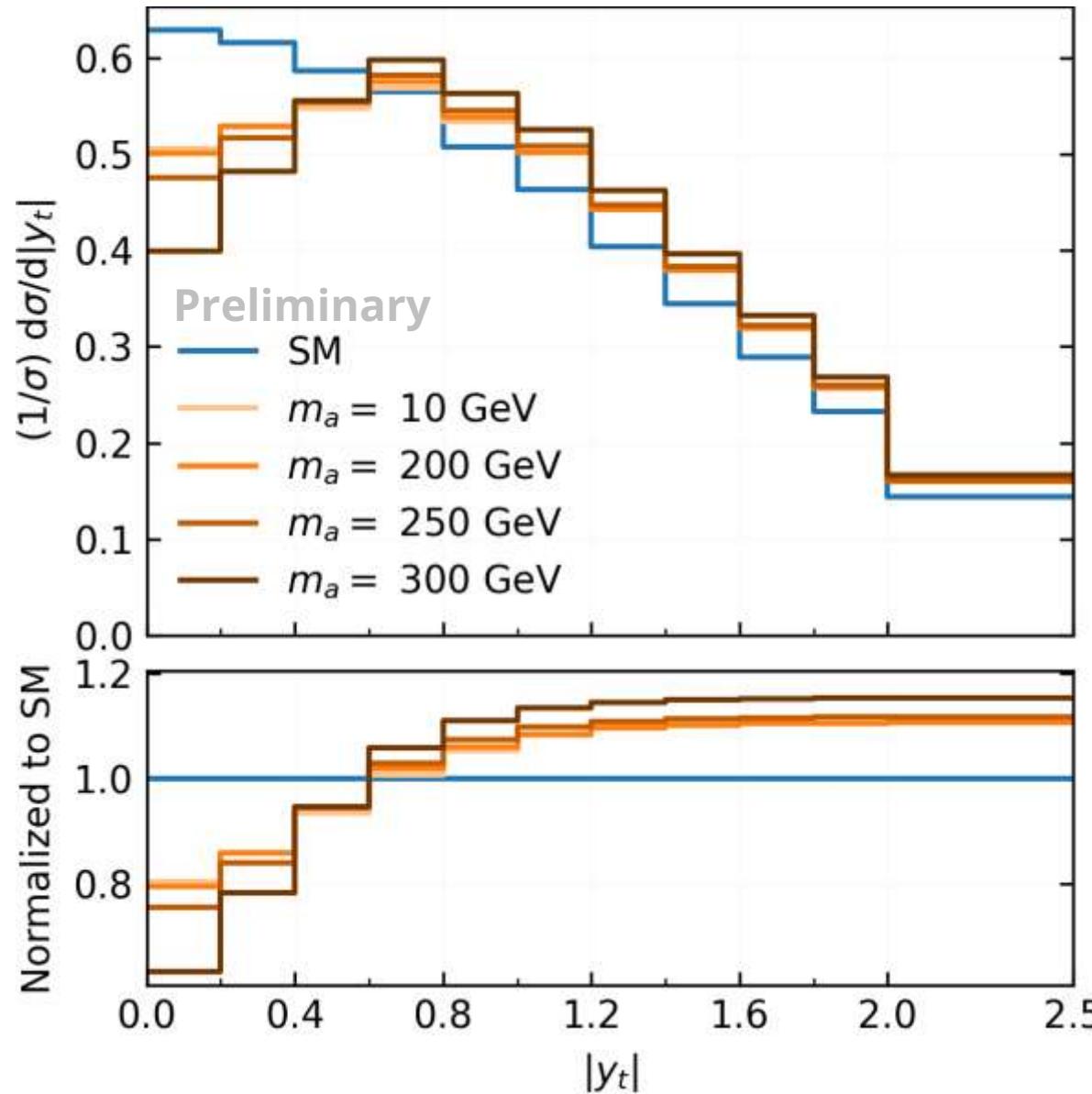
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RESULTS

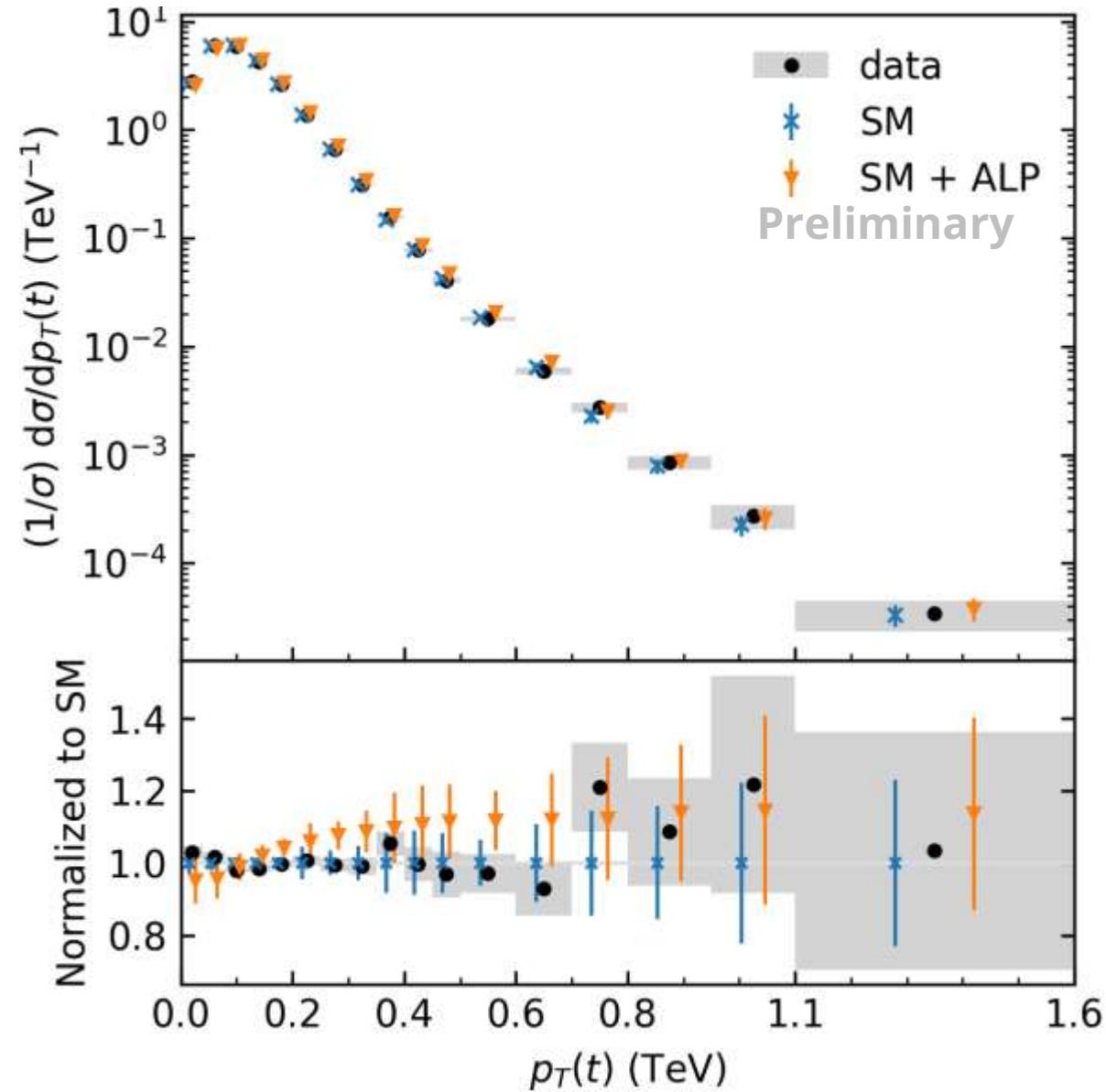
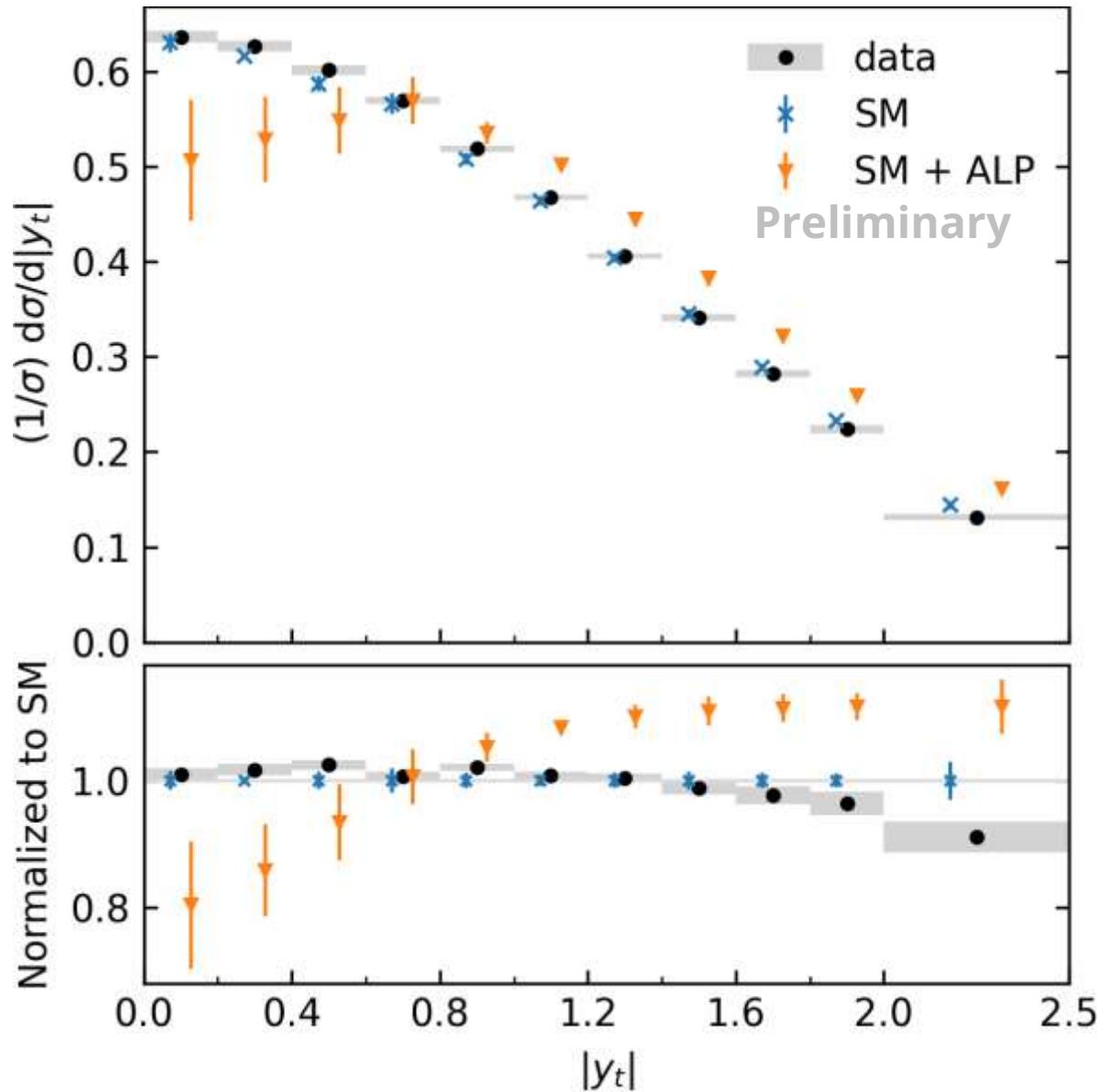
ALP MASS DEPENDENCE

$$\frac{c_{tt}(\Lambda)}{f_a} = 20 \text{ TeV}^{-1}; \tilde{c}_{GG}(\Lambda) = 0$$



Data: PRD 104 (2021) 092013
ALP uncertainty: 30%

$$\frac{c_{tt}(\Lambda)}{f_a} = 20 \text{ TeV}^{-1}; \tilde{c}_{GG}(\Lambda) = 0; m_a = 10 \text{ GeV}$$



RESULTS

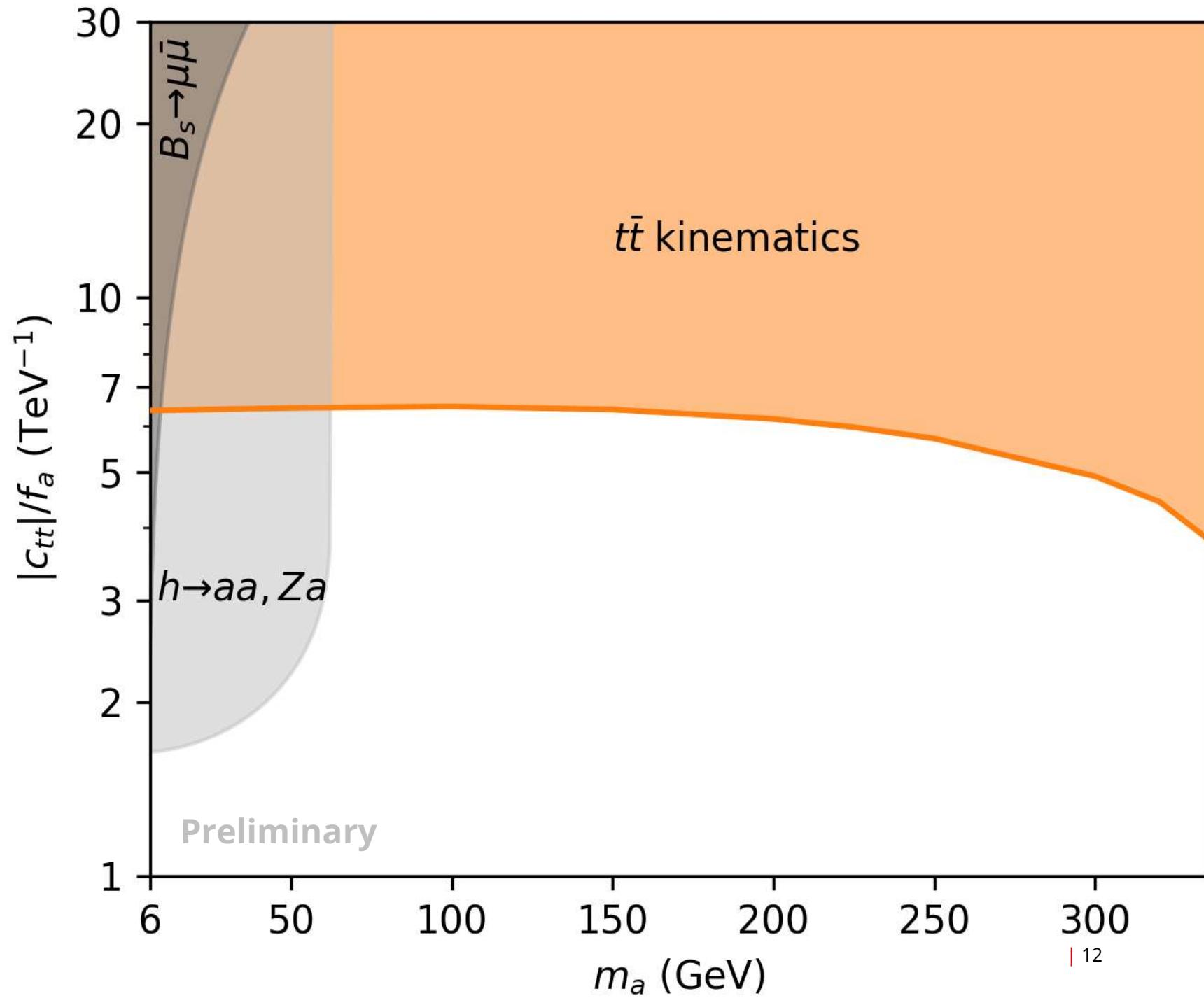
BOUNDS ON c_{tt}

$$\tilde{c}_{GG}(\Lambda) = 0$$

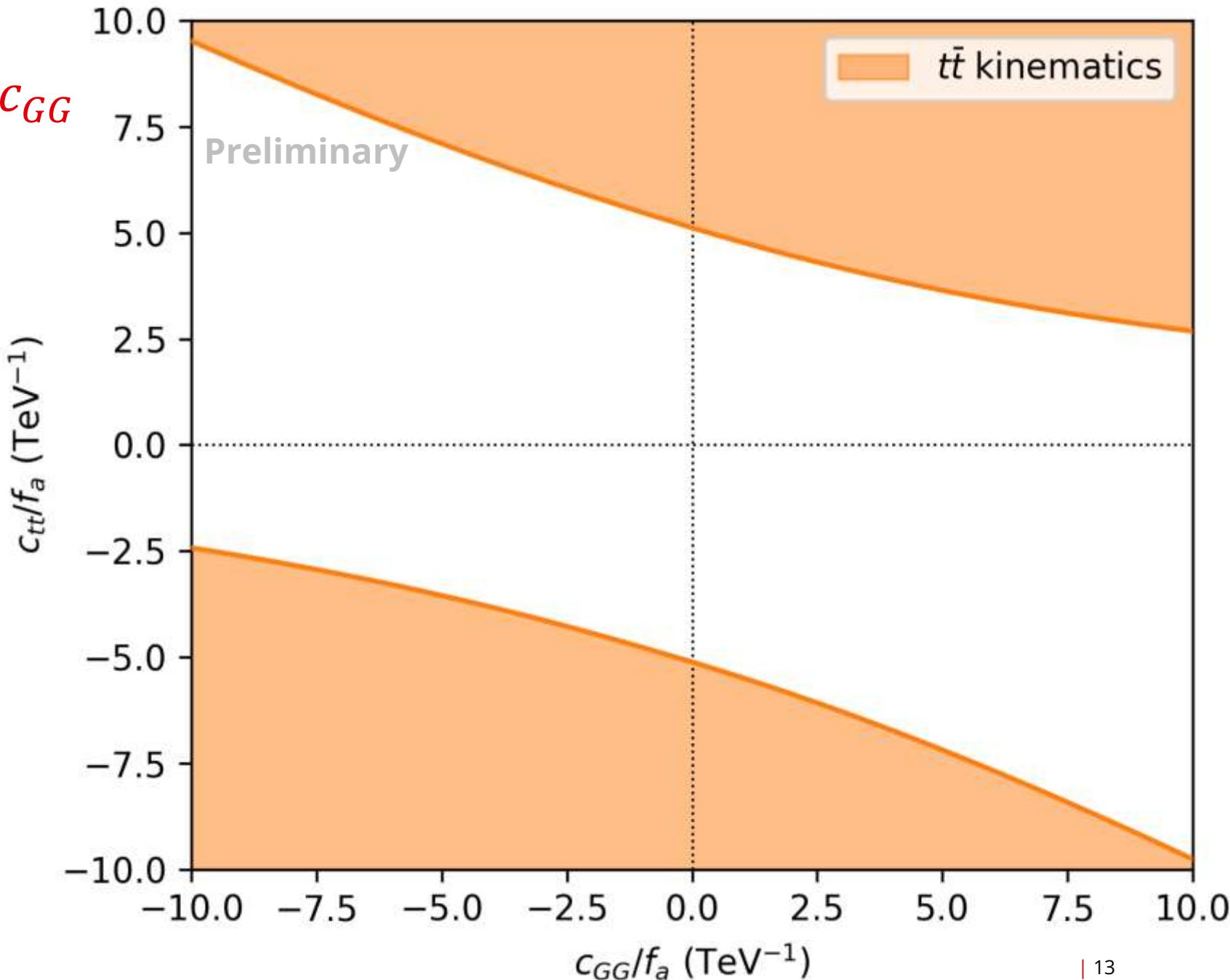
Shaded = excluded at 95% C.L.

Ref:

Bauer et al. (2021),
PDG (2023),
CMS-BPH-21-006,
DESY-14-026



RESULTS

BOUNDS ON c_{tt} AND c_{GG} $m_a = 10 \text{ GeV}$ 

Conclusions

- Among the SM fermions, **top is most sensitive to ALPs.**
- We constrain ALP-top coupling using top kinematic distributions.
- From a fit to LHC data Run II, we obtain $\left| \frac{c_{tt}}{f_a} \right| \leq 6.4 \text{ TeV}^{-1}$ for $m_a \lesssim 200 \text{ GeV}$ and $\tilde{c}_{GG} = 0$. This bound gets stricter as m_a approaches $2m_t$.
- ALP-gluon coupling can either enhance or suppress the ALP's effects, depending on its sign.

Thank you for listening!