CCC-DM

Collider-Cosmology Complementarity for Dark Matter

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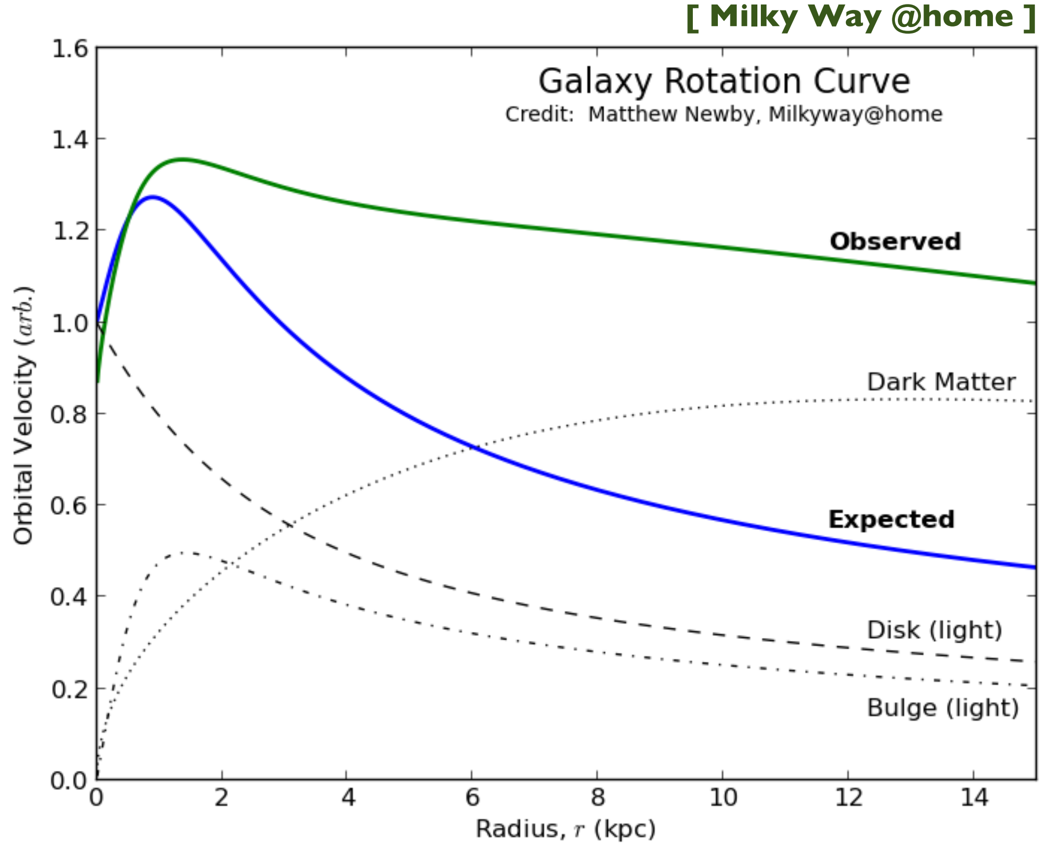
Evidence for dark matter

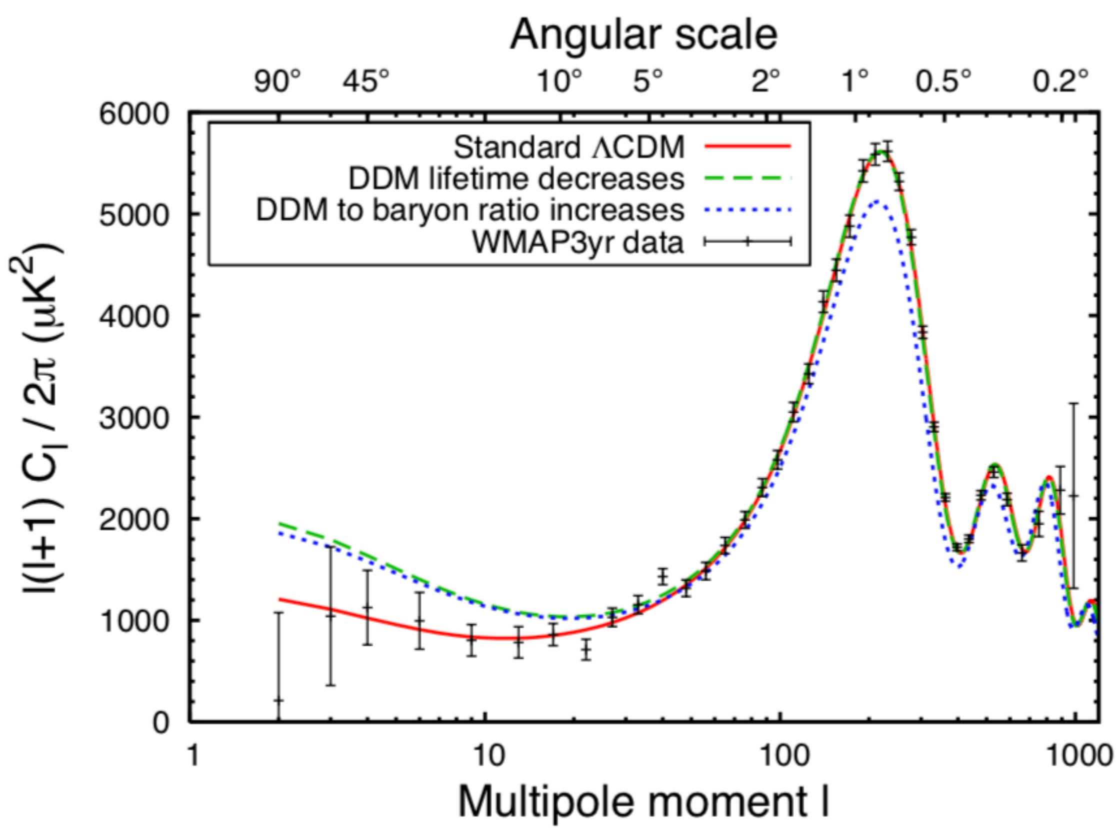
- ✦ Dark matter consists in an important motivation for new physics
  - ✤ Convincing evidence
    - ★ Flattening of the galaxy rotation curves
    - ★ Gravitational lensing
    - ★ Cosmic microwave background
    - ★ Structure formation
    - ★ *etc.*

Enormous endeavour to detect dark matter: directly, indirectly and at colliders

[Milky Way @home]



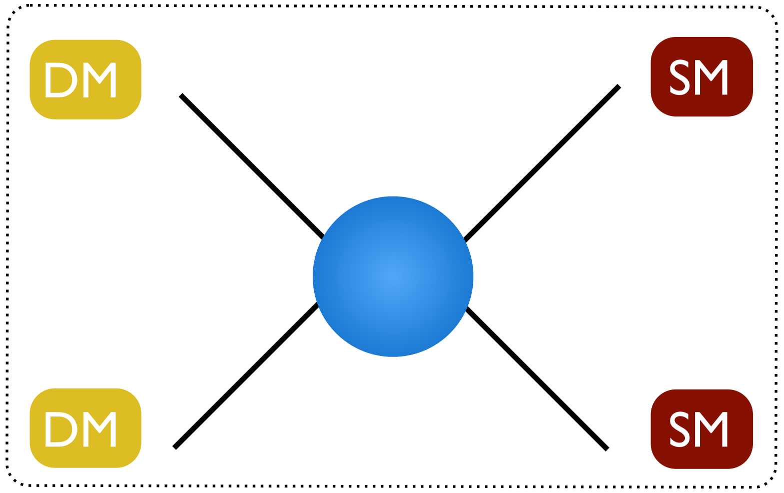
[Latanzi & Valle (PRL`07)]



Dark matter in cosmology and at colliders

- ✦ Dark matter is searched for directly, indirectly and at colliders
  - ✤ This huge experimental effort however offers a strategy to constrain models

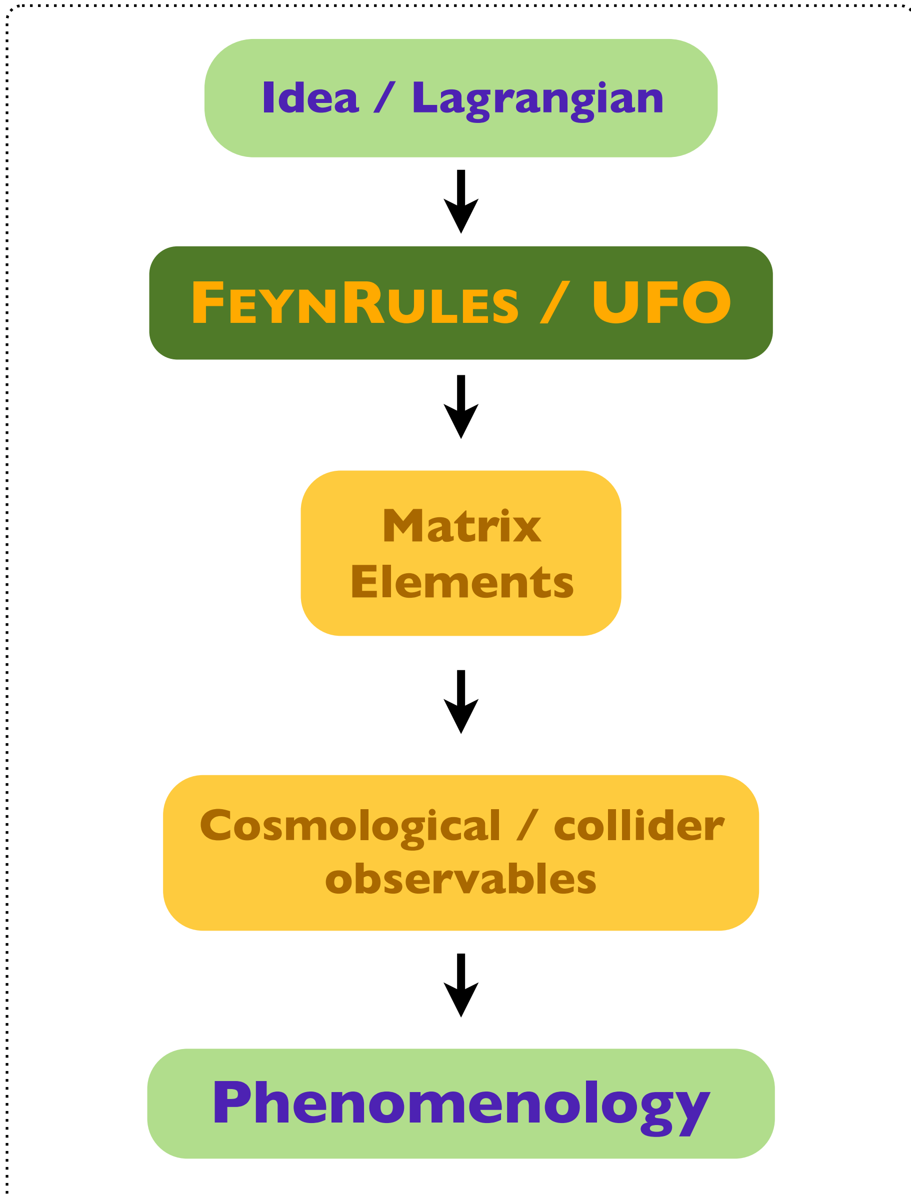
- ✦ Complementary between colliders and cosmology
  - ✤ Dark matter relic abundance must be reproduced
  - ✤ Constraints from dark matter direct/indirect detection
  - ✤ Direct production at colliders (missing energy)
- ✦ Current searches
  - ✤ Widely based on simplified models (but not only)
    - ★ Especially for what concerns LHC data analysis
    - ★ Potentially violating electroweak gauge invariance
    - ★ Need for UV-completions
  - ✤ CCC-DM: investigations of UV-complete models



A comprehensive approach to new physics calculations

[Christensen, de Aquino, Degrande, Duhr, BF, Herquet, Maltoni & Schumann (EPJC`11)]

✦ Connecting an idea to simulation tools



✤ Model building

- ★ Connecting a Lagrangian to code
- ★ FEYNRULES / UFO

[Alloul, Christensen, Degrande, Duhr, BF (CPC'14)]
[Degrande, Duhr, BF, Mattelaer & Reither (CPC'12)]

✤ Hard scattering

- ★ Feynman diagram and amplitude generation
- ★ Squaring of the matrix elements
- ★ CALCHEP (cosmology at LO)
- ★ MG5_AMC (colliders at LO and NLO)

[Belyaev, Christensen & Pukhov (CPC'13)]
[Alwall *et al.* (JHEP'14)]

✤ Cosmology

- ★ Annihilation cross section evaluation
- ★ Relic density, scattering off nuclei rates, *etc.*
- ★ MICROMEGAS / MADDM

[Bélanger, Boudjema, Goudelis, Pukhov & Zaldivar (CPC'18)]
[Ambrogi *et al.* (PDU'19)]

✤ Colliders

- ★ Recasting of LHC results; FCC prospects
- ★ MG5_AMC / MADANALYSIS 5

[Conte, BF, Serret (CPC '13);[Conte, Dumont, BF, Wymant (EPJC '14)]
[Dumont, BF, Kraml *et al.* (EPJC '15); Conte & BF (IJMPA`18)]

Example: scalar top-philic dark matter

✦ A simplified model for dark matter phenomenology

- ✤ To be considered as a toy model
- ✤ Useful tool to characterize given phenomena
  - ★ Reinterpretation made easy thanks to very few new parameters
- ✤ Reproduction of features shared by several UV-complete models

✦ The top quark is believed to play a special role

- ✤ Large mass ⇔ strong connection to electroweak symmetry breaking
  - ★ Setups featuring dark matter interactions with the top quark only

✦ Toy model inspired by compositeness

- ✤ Scalar dark matter and a fermionic mediator to the Standard Model

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm kin} + \Big[\tilde{y}_t\, S\; \bar{T} P_R t + {\rm h.c.}\Big]$$

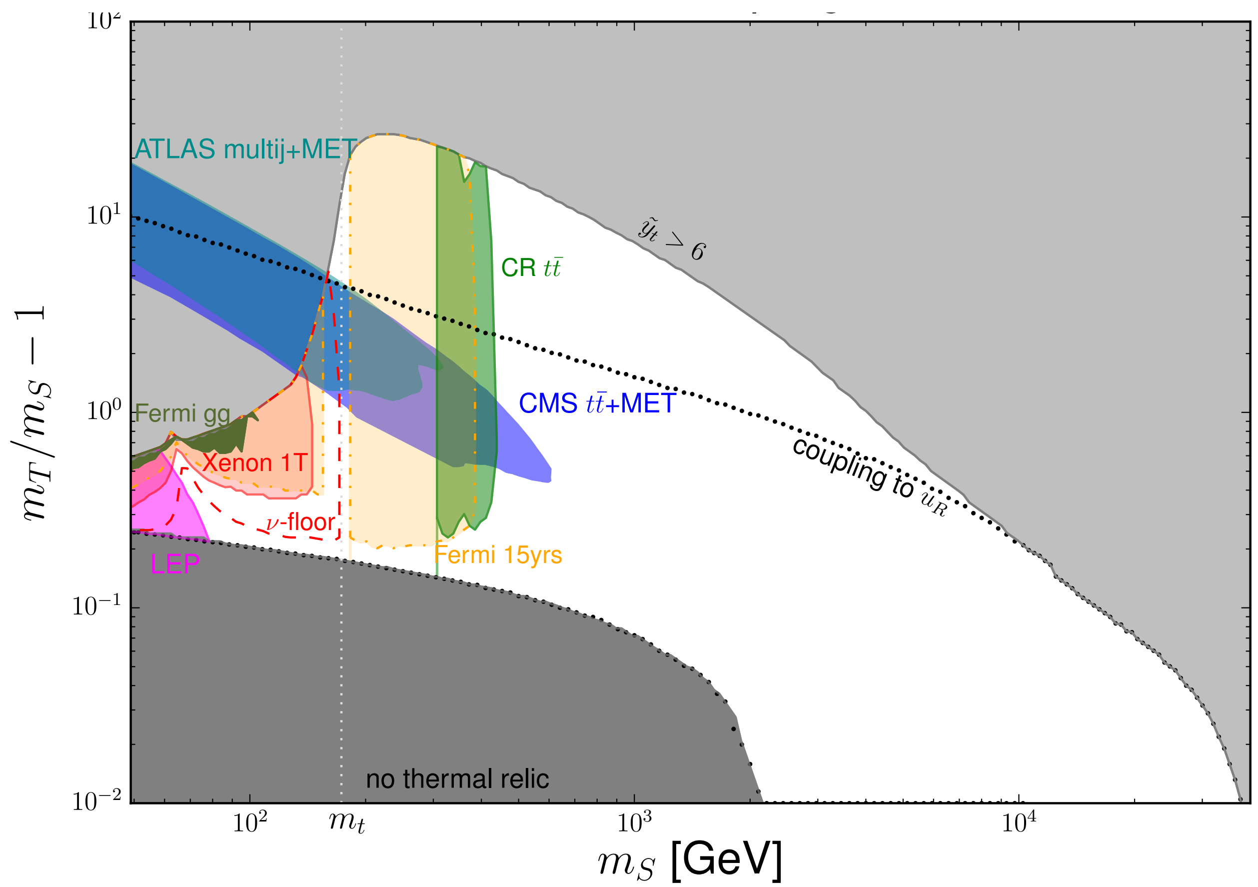
- ★ SU(2) singlet vector-like mediator T
- ★ EW singlet scalar dark matter S

- ✤ Simplified parameter space
  - ★ 2 masses: m_S, m_T/m_S-1; 1 Yukawa coupling $\tilde{y}_t$

Top-philic dark scalar matter with a VL mediator

[Colucci, BF, Giacchino, Lopez Honorez, Tytgat & Vandecasteele (PRD`18)]

✦ Collider-cosmology complementarily at work



✤ **Lagrangian**

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm kin} + \Big[\tilde{y}_t\, S\, \bar{T} P_R t + {\rm h.c.}\Big]$$

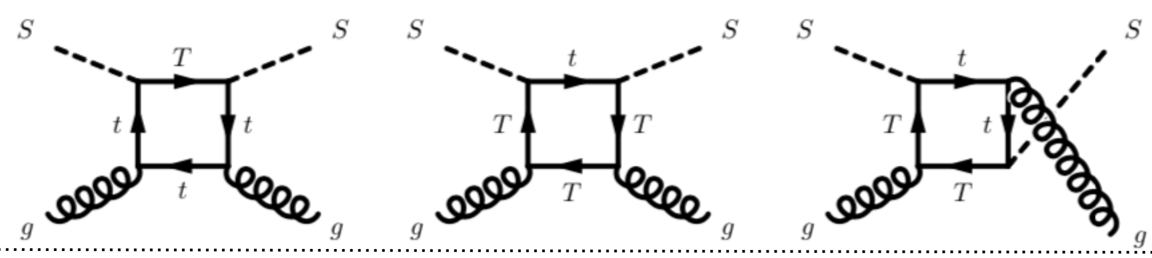
★ Vector like mediator *T*
★ Scalar dark matter *S*

✤ **Relic-density favored regions exist**

★ Fixes the Yukawa $\tilde{y}_t$
★ Dark grey: no thermal relic
★ Light grey: loss of perturbativity
★ Annihilation into gg below the m_t threshold

✤ **DM direct detection constraints**

★ Poor sensitivity (loop-induced interactions)
★ Most parameter space below the ν floor



✤ **DM indirect detection constraints**

★ Exclude (will rule out) limited light DM regions

✤ **Colliders** (present and future)

★ Sole probes to tackle the unconstrained regions

The CCC-DM roadmap

✦ Focusing on a UV-complete model

- ✤ Dilaton-assisted dark matter
- ✤ Standard dilaton couplings to the Standard Model fields
- ✤ Extra dark matter particle

[Csaki, Hubisz & Lee (PRD`07); Goldberger, Grinstein & Skiba (PRL`08)]
[Blum, Cliche, Csaki & Lee (JHEP`15)]

✦ Visible sector Lagrangian

- ✤ Effective theory with a scale invariance spontaneously broken at scale f
- ✤ The corresponding pseudo-Goldstone boson σ is the dilaton field

$$\begin{aligned}\mathcal{L}_{\rm eff} =& \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{2}m_\sigma\sigma^2 - \frac{5}{6}\frac{m_\sigma^2}{f}\sigma^3 - \frac{11}{24}\frac{m_\sigma^2}{f^2}\sigma^4 + \dots \\ & - \frac{\sigma}{f}\sum_\psi m_\psi\bar\psi\psi + \left[\frac{2\sigma}{f} + \frac{\sigma^2}{f^2}\right]\left[m_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2}m_Z^2 Z_\mu Z^\mu - \frac{1}{2}m_H^2 h^2\right] \\ & + \frac{\alpha}{8\pi f}c_\gamma\sigma F^{\mu\nu}F_{\mu\nu} + \frac{\alpha_s}{8\pi f}c_G\sigma G_a^{\mu\nu}G^a_{\mu\nu}\end{aligned}$$

✦ Connection with a (spin 0, 1/2 and 1) dark particle (S, χ,V)

$$\mathcal{L}_{\rm DM} = \mathcal{L}_{\rm kin} - \frac{1}{2}\left[\frac{2\sigma}{f} + \frac{\sigma^2}{f^2}\right]m_S^2 S^2 - \frac{\sigma}{f}m_\chi\bar\chi\chi + \frac{1}{2}\left[\frac{2\sigma}{f} + \frac{\sigma^2}{f^2}\right]m_V^2 V_\mu V^\mu$$

Working plans

✦ Implementation of the model in the simulation tools

✤ Considering all three dark matter spin options

✓ Mostly done

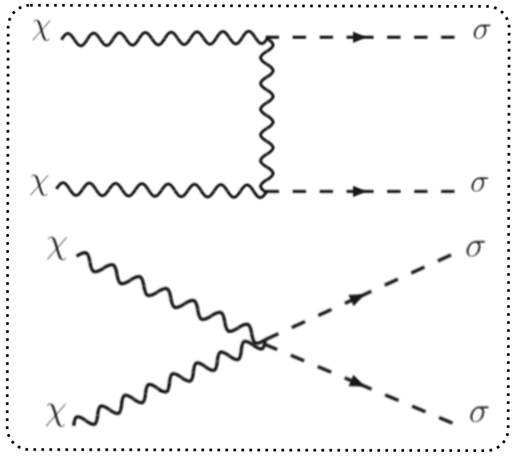
✦ Investigation of the current constraints on the model

✤ Dark matter relic abundance

✤ Dark matter direct and indirect detection

✤ LHC limit (recasting of various analyses) [→ *2017 workshop*]

✤ Update of the results already available in the literature



✦ FCC prospects

✤ Simplified setup based on the LHC

✤ More realistic setup with complete signal and background simulations

✦ Outcome

✤ One publication (end of 2019 / beginning of 2020)

✤ Presentation at conferences

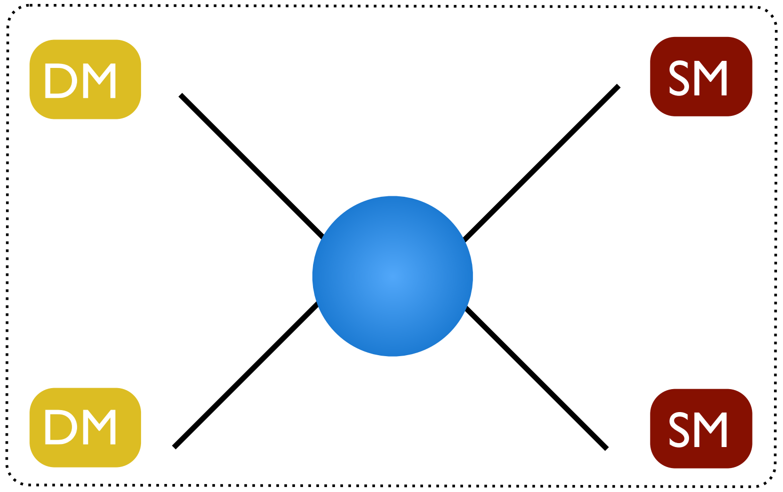
Summary

✦ Dark matter is searched for directly, indirectly and at colliders

- This huge experimental effort however offers a strategy to constrain models
- CCC-DM: focus on UV-complete models

✦ 2019: study of dilaton-assisted dark matter

- Expertise on these models
- Expertise on state-of-the-art simulation tools
- Collider and cosmology complementarity
- Current constraints and FCC prospects



✦ Agenda

- One mini-workshop in Paris (summer/fall 2019)
- One mini-workshop in Seoul (fall/winter 2019)
- Potential involvement of students/postdocs (both from France and Korea)

✦ Bonus

[B. Fuks *et al.*, arXiv:1806.02537 [hep-ph]]

- Organisation on a second MADANALYSIS 5 workshop on LHC recasting in 2020