Hunting for WIMP Minimal Dark Matter and New Charged Particles at a Future Muon Collider

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Introduction

In this talk I will highlight the results of a recent study of mine, *JHEP 10 (2023) 121*, which represents part of the activity for which I was recently hired as rtd-a at the University of Salento, supported by ICSC.

This study places in the context of the **design of future experiments,** in particular of new colliders, and is carried out thanks to the use and development of **Monte Carlo simulation codes and data analysis tools**

The aim is to analyze the **opportunities offered by a future Muon Collider** to address questions related to two fundamental puzzles in fundamental High-Energy Physics:
The presence of **New Physics** connected to a more complete understanding of the **EWSB Higgs mechanism**
and the origin of the **Dark Matter** of the universe

A Future Muon Collider

D. Stratakis et al. (Muon Collider), A Muon Collider Facility for Physics Discovery, (2022), arXiv:2203.08033; K. M. Black et al., Muon Collider Forum Report, (2022), arXiv:2209.01318 [hep-ex].; C. Accettura et al., Towards a Muon Collider, (2023), arXiv:2303.08533 [physics.acc-ph]
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mu+ mu- in a circular collider with a ring of the size of the LHC, 27 Km (possibly using the LHC ring)

Energy and Luminosity design targets:

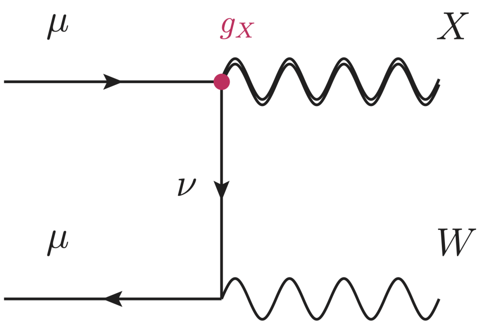
$\sqrt{s} = 1, 3, 10, 30, 50 \text{ TeV} \qquad L = 0.1, 0.9, 10, 90, 250 \text{ ab}^{-1} \qquad L = 10 \left(\frac{\sqrt{s}}{10\,\text{TeV}} \right)^2 \text{ab}^{-1}$

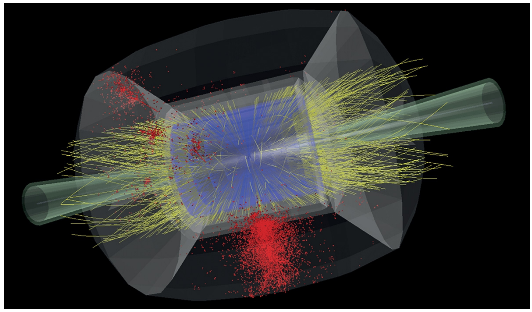
Advantages:

- typically higher effective collision energies (hadron colliders pay for PDFs, e+e- for sinchrotron radiation effects)
- lower background (compared to hadron colliders)

Main challenge: short life-time of muons

W associated production at a Muon Coll



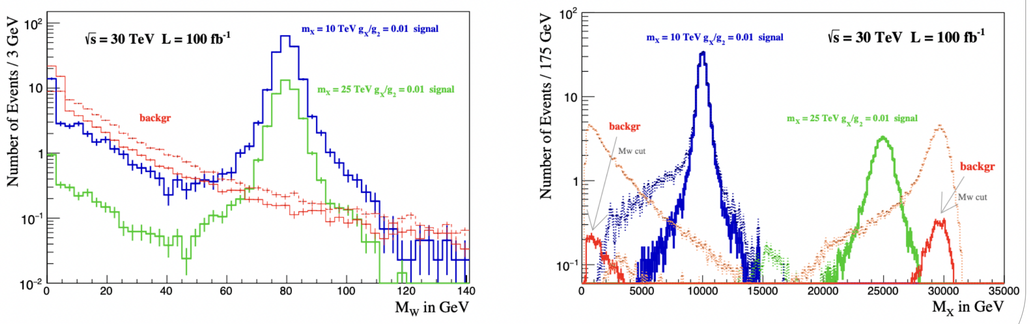


$$\mathcal{L}_{eff}^{W'} = \frac{g_X}{\sqrt{2}} \left[V_{ij}^{CKM} \bar{u}_i \gamma^\mu P_L d_j + V_{ij}^{PMNS} \bar{\nu}_i \gamma^\mu P_L \ell_j \right] X_\mu + H.c.$$

PARTICLE PHYSICS DESCRIPTION

need the use and development of codes **in Mathematica Wolfram** and **Python** (input to, and use of, *MadGraph* simulation tool)

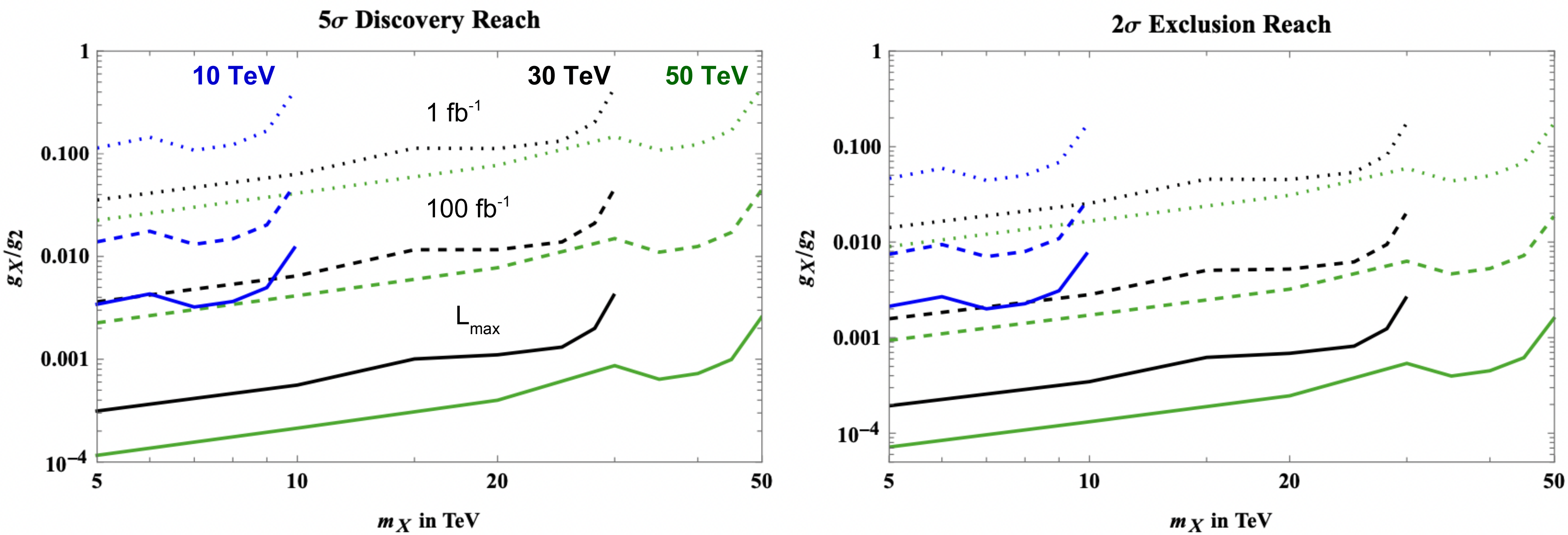
CALCULATIONS AND EVENT SIMULATIONS



Design of an analysis strategy which crucially involve **C++ coding** (performed within *CERN ROOT* analysis tool)

RESULTS

MuCol Reach in the W+X channel



In general, **charged resonances** ca be tested up to multi-TeV mass values close to the collision energy, and for **very small couplings** with the SM fermions, of the order of 10^{-3} - 10^{-4} times the SM weak coupling.

➡ **unprecedented level for a direct search** (FCC-hh reach ~1-2 orders of magnitude lower than 10 TeV MuCol reach [CERN Yellow Rep. (2017) 3])

A 5-plet **Minimal Dark Matter** bound state can be excluded with about 34 fb^{-1} and discovered with 210 fb^{-1} by a 30 TeV muon collider

Conclusions

High computing tools and resources can allow to address crucial puzzles in particle physics and can guide the developments of new experiments (future colliders)

- In particular, we find that **a multi-TeV muon collider** is very efficient not only for the search for new heavy neutral particles, but also for the **discovery of charged bosons of the W′ type.** By analyzing the associated production with a Standard Model W, charged resonances can be probed directly up to multi-TeV mass values close to the collision energy, and for very small couplings with the SM fermions marking an unprecedented level of sensitivity for a direct search.
- Furthermore, the channel offers a very efficient and alternative way to probe the **WIMP scenario** for the very special and compelling case of Minimal Dark Matter (MDM) in the 5-plet EW representation, by allowing the direct detection of the charged component of the MDM bound state. The reach on the WIMP 5-plet thermal target is found to be much higher than those of mono-X, missing-mass and disappearing tracks signatures.