Dark Matter Scattering[1]

in Sp(4) on the lattice

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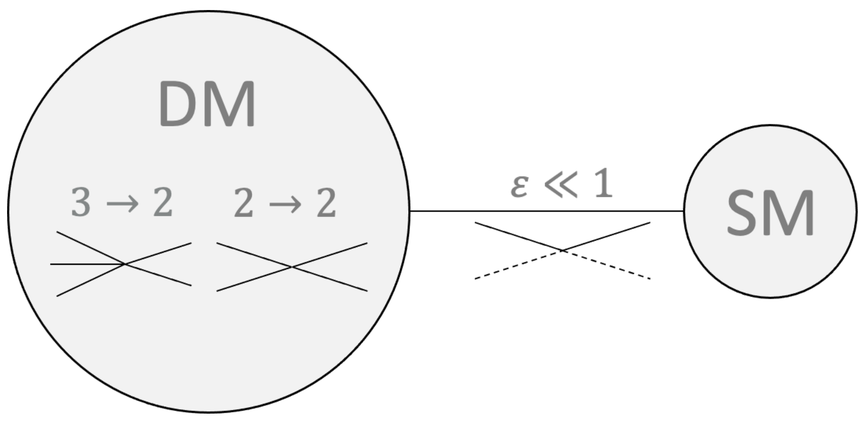
X-ray: NASA/CXC/CfA/M.Markevitch et al.

Dark Matter interaction

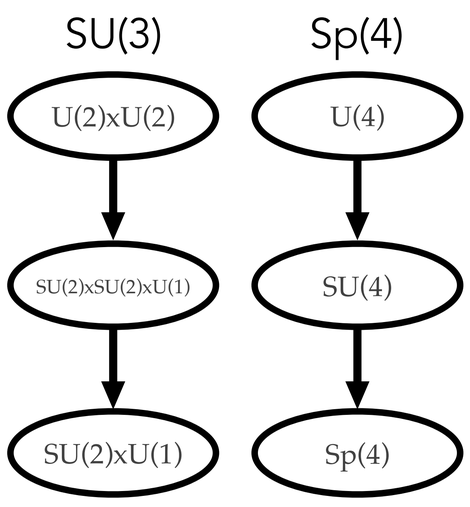
- A particle beyond the standard model is a promising candidate for dark matter. Such a particle has to be massive, stable and *invisible*.
- "Small scale structure problems"[2] indicate a self-interaction within the dark sector. But there are also upper bounds, i.e. coming from the *bullet cluster*.
- Recent fits to halo simulations prefer a velocity dependent cross-section[3].

Strongly Interacting Massive Particles

- The SIMP[4] paradigm offers a new possibility of dark matter as a thermal relic from the early universe.



- It contains a number-lowering process in the dark sector ($3 \to 2$). In an effective description[5], this can be described by the *Wess-Zumino-Witten* term. To prevent heat-up, a mediator to the standard model has to be introduced.
- A minimal SIMP-realization is $Sp(4)_c$ with N_f=2 fundamental fermions, which enhances the flavour symmetry to $Sp(4)_f$. Left- and right-handed fermions mix to give so-called Weyl fermions. Because N_c is even, we have no fermionic bound states.



- The dark matter candidates are the 5 pNGBs from chiral symmetry breaking - *dark Pions*. On top of that there is a zoo of particles: 10 Rho mesons, singlets …
- Sp(4) is also a candidate theory for composite Higgs models or to describe early universe phase-transitions from beyond the standard model theories. The results shown here may also be used for these purposes.

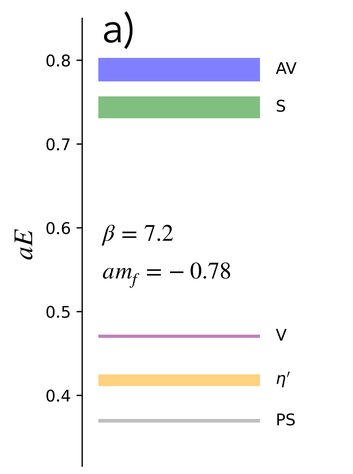
Scattering on the lattice

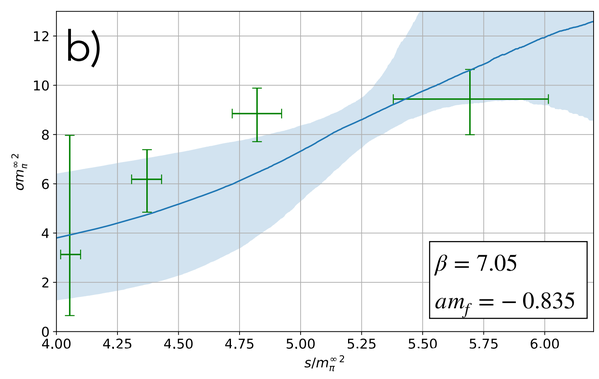
- On the lattice, *infinite volume* scattering properties can be extracted from the *finite volume* energy levels[6]. This is commonly referred to as the Lüscher quantization condition. The result is a one-to-one correspondence between the energy levels and the cross-section.
- The framework for an extension to three particle scattering already exists and can be applied to the $3 \to 2$ process[7].

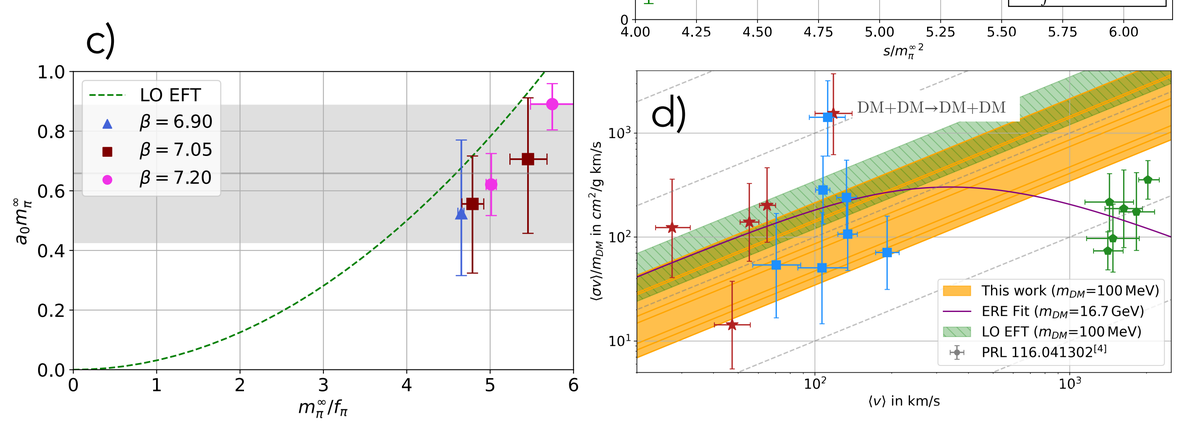
Results

Simulated with the HiRep code for symplectic gauge groups using standard Wilson fermions

- There is a rich particle spectrum, just like in QCD, where each particle is probed by different quantum numbers, which has been analyzed in previous work[8]. For the Lüscher-analysis, $\pi\pi$ -operators have to be employed.
- In this work, we only look at s-wave scattering in the most common channel and compare results directly to astrophysical data. Close to threshold, we use effective range expansion to extract the scattering length.







a) Energy spectrum[8], b) Cross section, c) Scattering length vs ChPT, d) Velocity-weighted cross-section

- We find decent agreement with ChiPT and match astrophysical data at $m_{DM} \sim 100\,\text{MeV}$ which is predicted for SIMP-models. We do not see a sign for a velocity dependence. However, due to the systematics involved, this result alone does not invalidate Sp(4) dark matter.

References

[1] This work - arXiv.2405.06506 (2024)
[2] Tulin, Yu - Rhys. Rept. (2018)
[3] Kaplinghat et al. - Phys. Rev. Lett (2016)
[4] Hochberg et al. - Phys. Rev. Lett. (2015)
[5] Kulkarni et al. - SciPost (2023)
[6] Briceño et al. - Rev. Mod. Phys. (2018)
[7] Hansen, Sharpe - Phys. Rev. D (2014)
[8] Bennett et al. - Phys. Rev. D (2024)

Outlook

- $\pi\pi \to \rho$ resonant scattering.
- Translate the scattering matrix of $\pi\pi\pi \to \pi\pi$ from WZW in ChPT to finite volume energy levels.

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