Light WIMPs and MeV Gamma-ray Detection with COSI

arXiv:2504.11810

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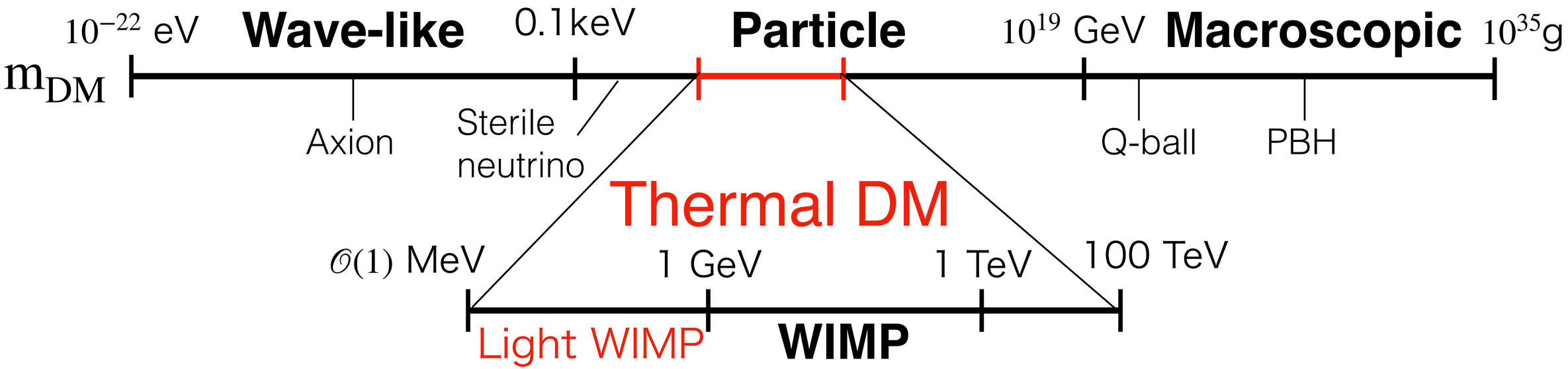
DM candidates

Mass range spans almost
90 orders of magnitudes…

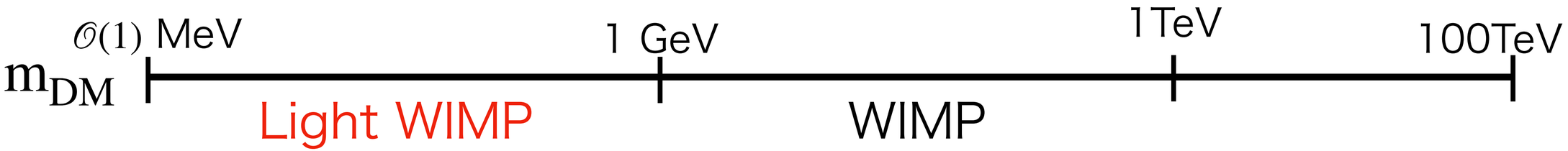


- ∃ Various candidates, and one of the most attractive candidate is the thermal DM.

  Def: Experienced equilibrium with SM particles in the early universe.

  Motivation:
  - Free from the initial condition problem of $\rho_{\rm DM}$.
  - Detectable based on the interaction maintaining equilibrium.
  - $\rho_{\rm DM}$ can be from the freeze-out mechanism.

Motivation of light WIMP



- **Theoretical viewpoint**
  - At first, WIMP has been intensively searched for, however not found.
  - ∴ Different mass region, light WIMPs, are getting more attention.

- **Experimental viewpoint**
  - Many experiments are being planned to search for the light DM.
  - The MeV γ-ray detection is an advancing field. ∃ 'MeV' gap, but COSI was approved.
  - ∴ Studying DM producing MeV γ-ray is important.

Only approved
MeV γ-ray telescope

Goal: Studying light WIMPs complehensively and figuring out whether COSI can probe them.

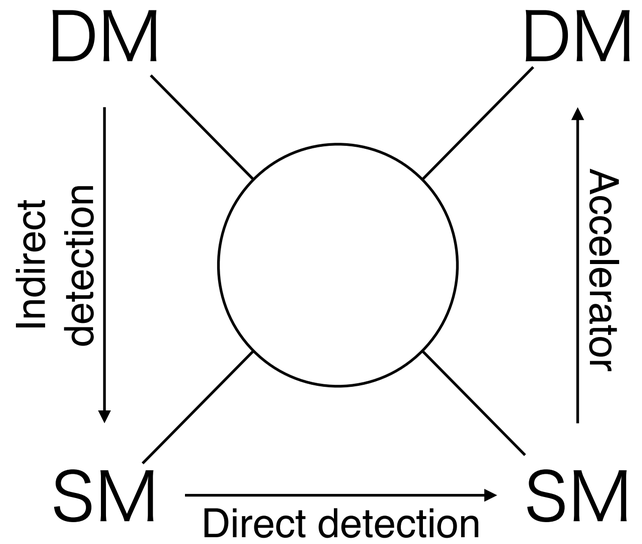
Light WIMP models

- What model is favored with the minimlaity, renormalizability and Z_2 symmetry?
- Theoretically viable model is SM + singlet DM + singlet mediator.
  - DM should be singlet under SM gauge group. ($\because$ Relic abundance)
  - Minimal model (SM + scalar DM: Higgs portal) was already excluded.
  - MED should be singlet ($\because$ Collider) and $\mathrm{m_{MED}} \sim \mathrm{m_{DM}}$. ($\because$ Relic abundance)
- We assume DM is a scalar or fermion and MED is a scalar or vector. We consider the dark photon and $\mathrm{U(1)_B}$ boson for the vector MED.
- We name these models as:

DM \ MED	Scalar	Vector (DP)	Vector (U(1)B)
Scalar	SS	SV(DP)	SV(B)
Fermion	FS	FV(DP)	FV(B)

We investigated all the models to figure out if ∃ viable parameter regions surviving from various constraints and if COSI can probe them.

Experimental constraints



- ∃ 3 types of DM-SM interaction, and ∃appropriate searching strategy for each.

Direct detection (Observation of DM-SM scatterings at underground laboratories)

- Traditional experiments (Xenon, etc.) lose the sensitivity for the light DM, as the recoil energy is small then falls below the detector threshold.
- ∃ Several strategies: detector with low threshold, Migdal effect, electron scattering.

Accelerator (Production of DM by high energy SM particles collisions)

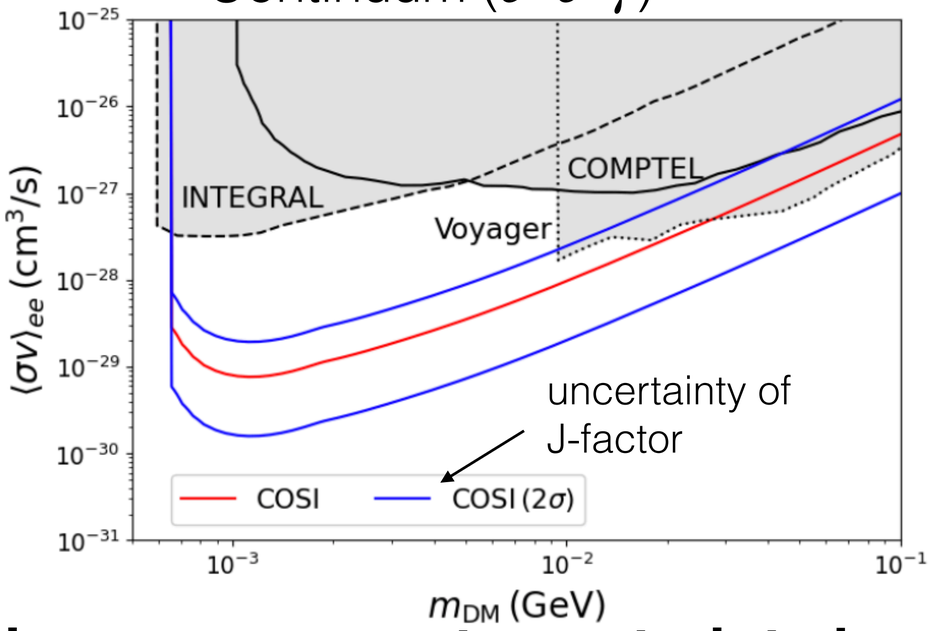
- ∃ many types (collider, fixed target, beam dump) and accelarating SM particles (e and p).
- ∃ many signals (Higgs invisible decay, MED production (invisible decay, visivle decay)).

We have implemented all the constraints.

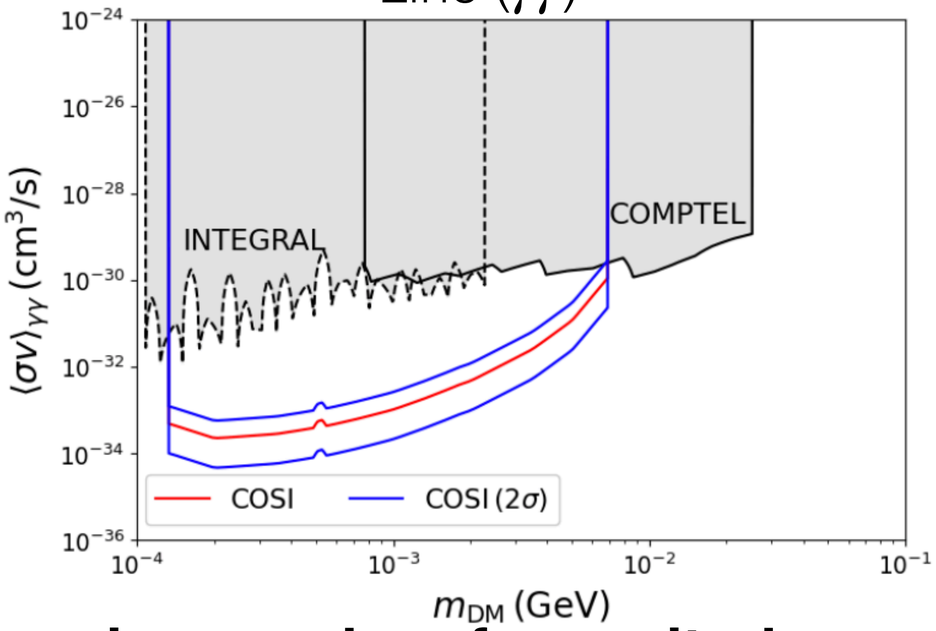
Indirect detection (Observation of SM particles produced by DM annihilations in the universe)

- Light thermal DM can annihilate into e^+e^- (+ FSR γ), $\gamma\gamma$ and $\pi^0\gamma$.
- Low energy $e^\pm$ cannot enter the heliosphere by the solar magnetic field. Only Voyager I can detect this.
- MeV γ-ray is difficult to detect ('MeV gap'), resulting in the usage of only old experiments (COMPTEL, INTEGRAL).
- We estimated the COSI sensitivity (2 years observations of the GC ($|\theta| < 10°$)), assuming the NFW profile.

Continuum ($e^+e^-\gamma$)



Line ($\gamma\gamma$)



COSI can improve present constraints by nearly an order of magnitude

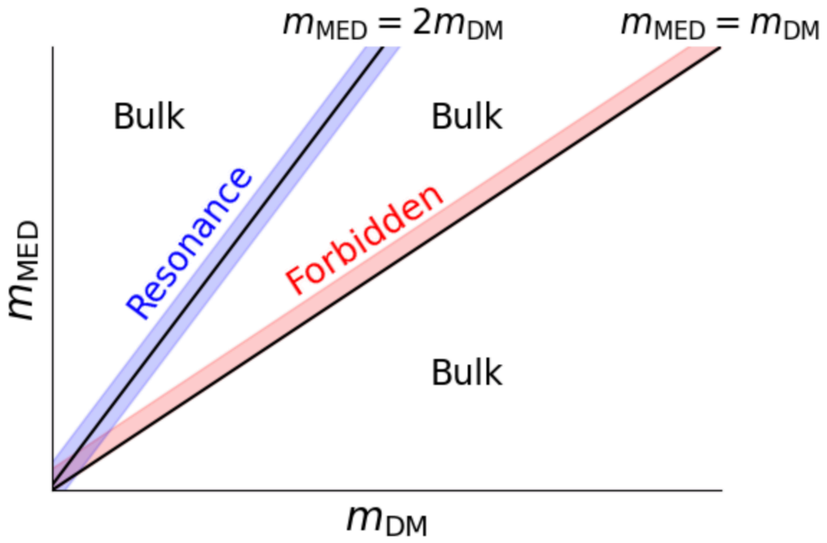
Cosmological constraints

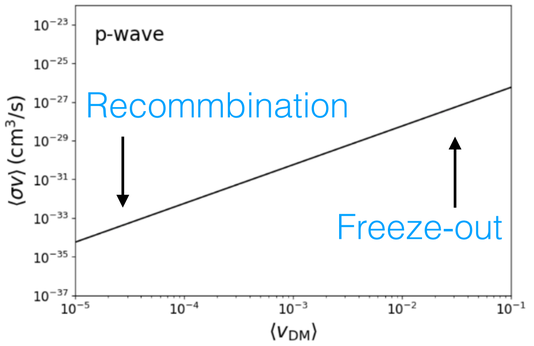
- ∃ many constraints… We implemented all the constraints.
- **Lyman - α**
  - Late kinetic decoupling of DM suppresses the structure formation,resulting in $T_{\rm kd} \gtrsim 200$ eV.
- **BBN**
  - **Constraint on $m_{\rm DM}$:** Light thermal particle affects $T_{\gamma(\nu)}$ and the expansion rate, then light element abundances. $m_{\rm DM} \gtrsim \mathcal{O}(0.1)\,{\rm MeV}$
  - **Constraint on $\langle\sigma v\rangle$:** Photons emitted by DM annihilations may destroy the light elements. Deutrium abundance results in $\langle\sigma v\rangle \lesssim 10^{-24}{\rm cm}^3/{\rm s}$ $(m_{\rm DM} \gtrsim 2\,{\rm MeV})$ @ $T_\gamma \sim \mathcal{O}(1)$ keV.
- **CMB**
  - **Constraint on $m_{\rm DM}$**: Asymmetrical entropy injection into EM-plasma and ν alters expansion rate of universe. $m_{\rm DM} \gtrsim \mathcal{O}(1)\,{\rm MeV}$
  - **Constraint on $\langle\sigma v\rangle$**: DM annihilations into primordial plasma may modify the anisotropy of the CMB. $\langle\sigma v\rangle \lesssim 10^{-27}{\rm cm}^3/{\rm s}\,({\rm m_{DM}/GeV})$ @ recommbination
  - **Relic abundance:** $\langle\sigma v\rangle \approx 10^{-26}{\rm cm}^3/{\rm s}$ @ freeze-out.

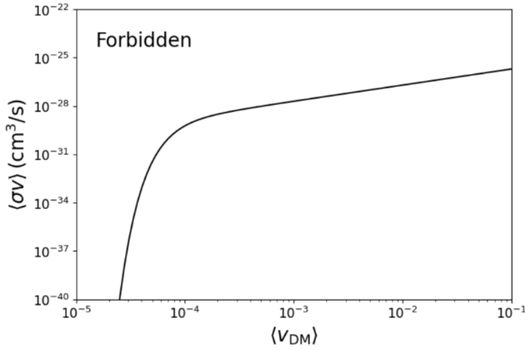
← Simple s-wave annihilaltion is not good.

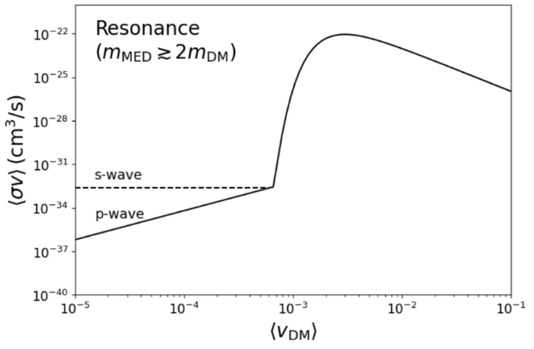
Variable regions and What we did

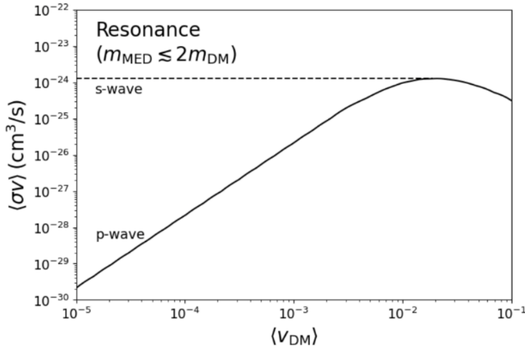
- $\langle\sigma v\rangle \lesssim 10^{-27}\mathrm{cm}^3/\mathrm{s}$ @1 eV $\leftrightarrow$ $\langle\sigma v\rangle \approx 10^{-26}\mathrm{cm}^3/\mathrm{s}$ @ $m_{\mathrm{DM}}/20$.
- Thanks to the ∃ MED, ∃ 4 regions with velocity-dependent $\langle\sigma v\rangle$











We have 6 models, and 4 regions, i.e. 24 regions as listed in the table. For each,

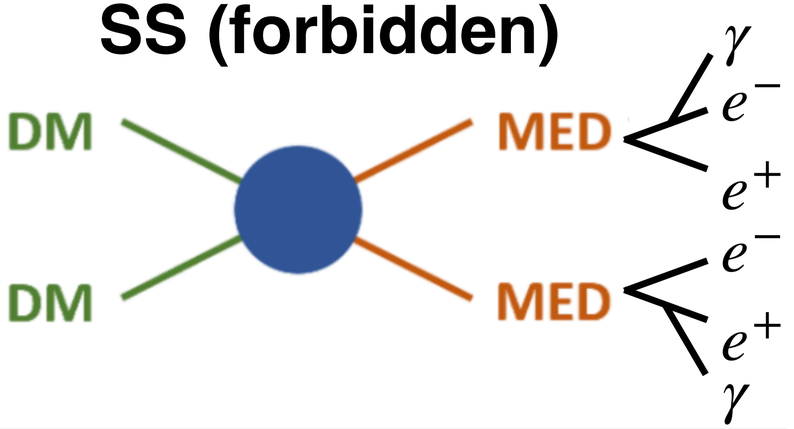
1. **We wrote codes which implement all mentioned constraints, and find surviving parameter sets.**
2. **We casted them to the experimental observables, and figure out if COSI can find them.**

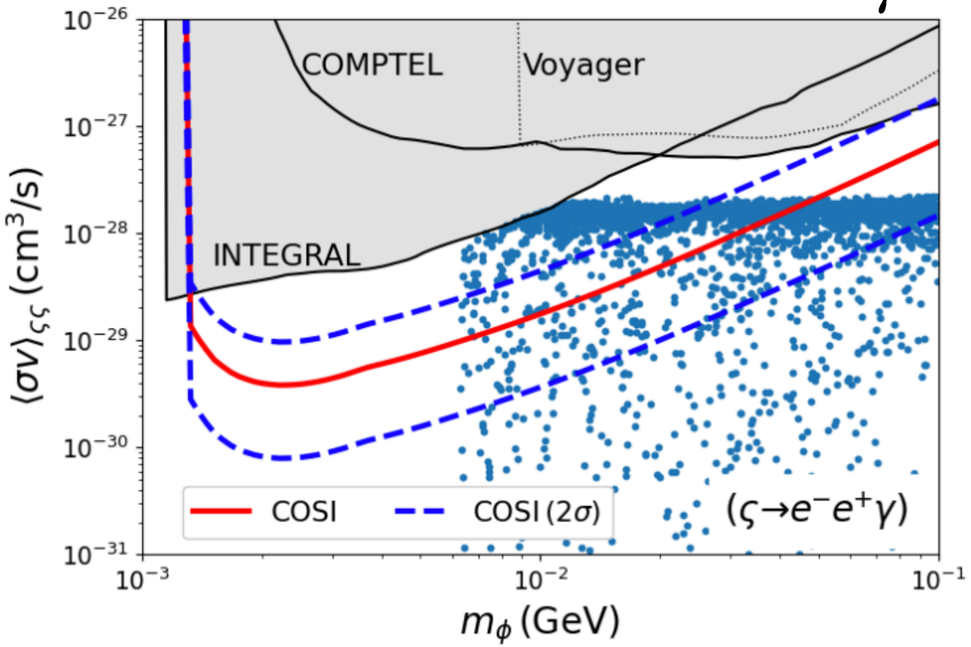
	SS	FS	SV(DP)	FV(DP)	SV(B)	FV(B)
Bulk	✓	✓	✓	✓	✓	✓
Forbidden	✔	✓	✓	✓	✓	✓
Resonance(vis)	✓	✓	✓	✓	✓	✓
Resonance(inv)	✓	✓	✓	✓	✔	✓

We have explored all models.
✔⋯ I'll show the result as Ex. in the next slide.

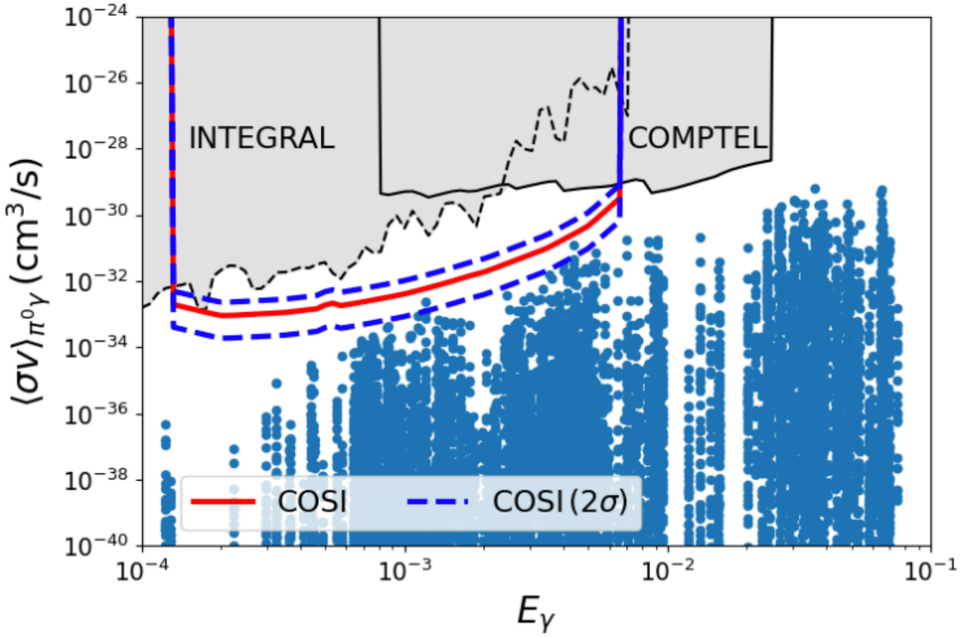
Ex. results

SS (forbidden)





SV(B) (resonance)



COSI can detect viable parameter sets which cannot be probed by current experiments.

Summary

- **Light WIMps are** getting more and more attention.
- **COSI** was approved, and the MeV γ-ray detection is an advancing field.
- We for the first time considered all possible models of light WIMPs phenomenologically.
- COSI has the potential to probe a wide range of viable parameter sets:

	SS	FS	SV(DP)	FV(DP)	SV(B)	FV(B)
Bulk	–	○	○	–	–	–
Forbidden	○	○	○	○	–	–
Resonance(vis)	–	–	○	–	–	–
Resonance(inv)	–	–	○	○	○	○

○ ∃ surviving parameters

○ COSI can detect continuum γ-ray

○ COSI can detect continuum and line γ-ray