Supernova bounds on new scalars from resonant and soft emission

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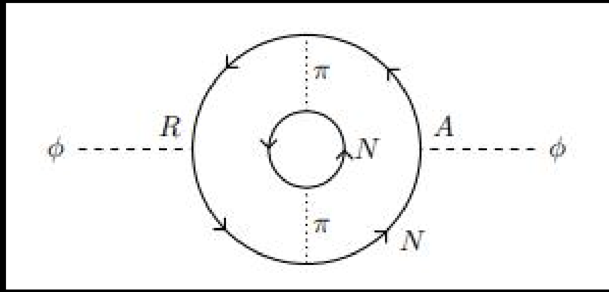
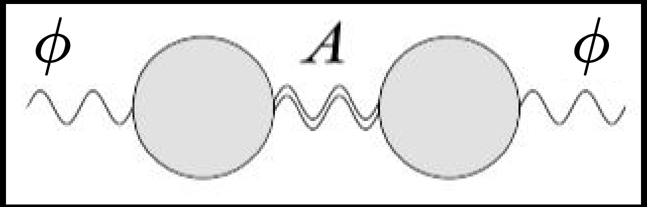
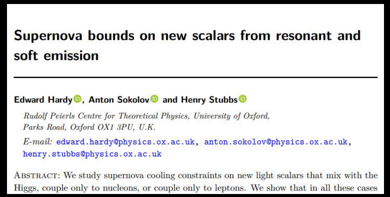
[E Hardy, AS, H Stubbs, JHEP ‘25]






Supernova bounds on new scalars from resonant and soft emission

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ABSTRACT: We study supernova cooling constraints on new light scalars that mix with the Higgs, couple only to nucleons, or couple only to leptons. We show that in all these cases

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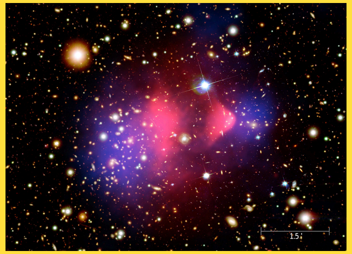
OUTLINE

- Why scalars
- Why supernovae
- In-medium rates of emission and RESONANCE
- Astrophysics: model and uncertainties
- SN 1987A confronts scalars

WHY SCALARS

- Dark matter

ΛCDM


NASA image


ESO/Illustris Collaboration

What makes Cold Dark Matter ?!

$\Rightarrow$ axions
dark photons
scalars
...

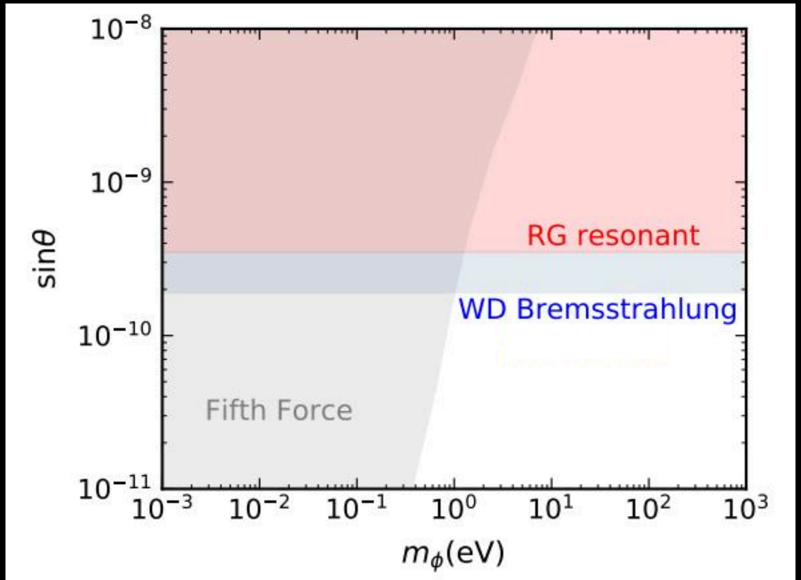
- As minimal assumptions as possible $\Rightarrow$ no extra charged/gauge fields

spin-0

SCALAR
Φ

Higgs portal

MIXING PARAMETER VS MASS: PARAMETER SPACE FOR SCALARS



SCALAR

Φ

→ Higgs portal

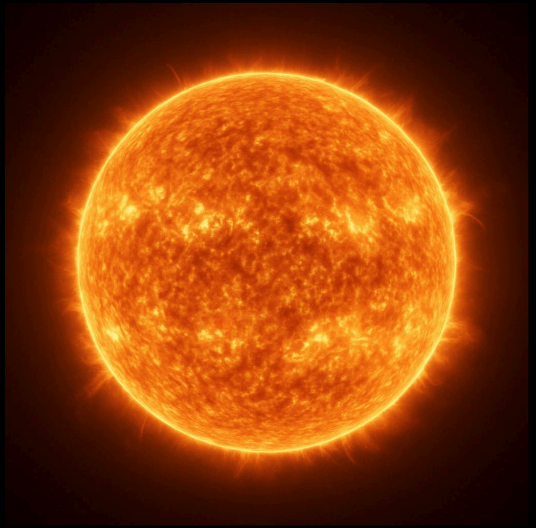
$$(\lambda_1 \Phi + \lambda_2 \Phi^2) H^\dagger H$$

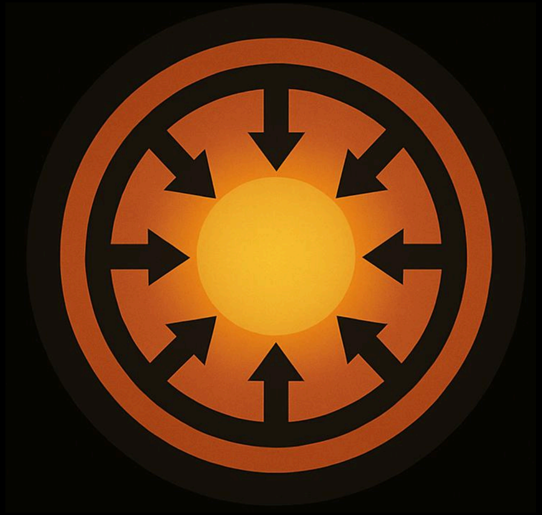
$$\sin\theta \frac{m_f}{v} \phi \bar{f} f$$

f is every Standard model fermion

ASTROPHYSICS CONFRONTS SCALARS: TEMPERATURE VS MASS

$$\phi\text{–production rate at large masses} \sim \exp(-\,\text{MASS}\,(\phi)/T)$$





T ~ 1 keV

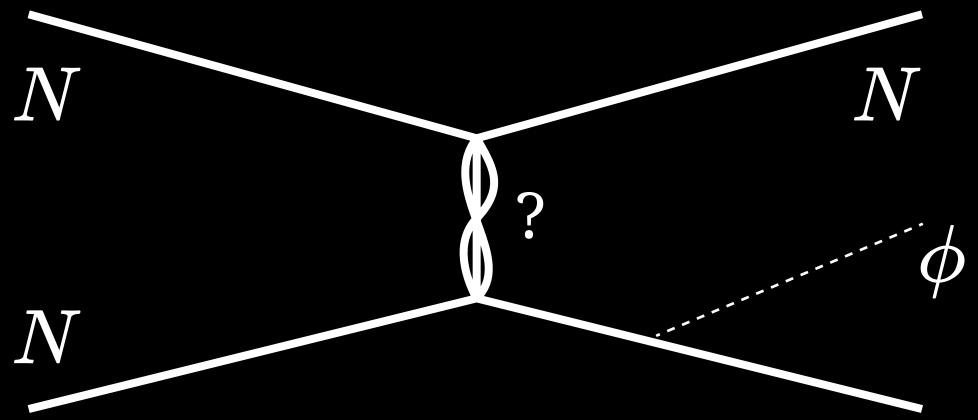
T ~ 10 keV

T ~ 30 MeV

- Supernovae are ideal laboratories to probe MASSIVE scalars

PRODUCTION OF SCALARS IN PLASMA

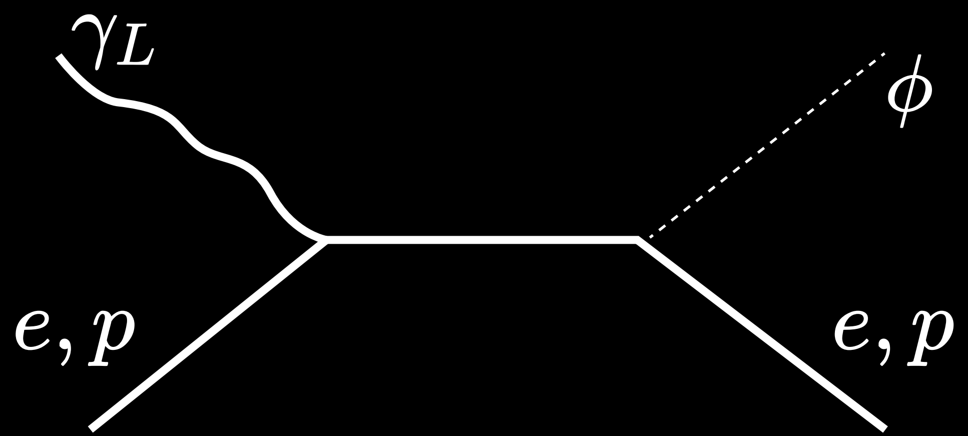
Nucleon-nucleon bremsstrahlung



Strong interaction $\Longrightarrow$ no analytic control

BUT: **soft** approximation allows to factorize
$\Longrightarrow$ use NN $\rightarrow$ NN cross-section
known experimentally

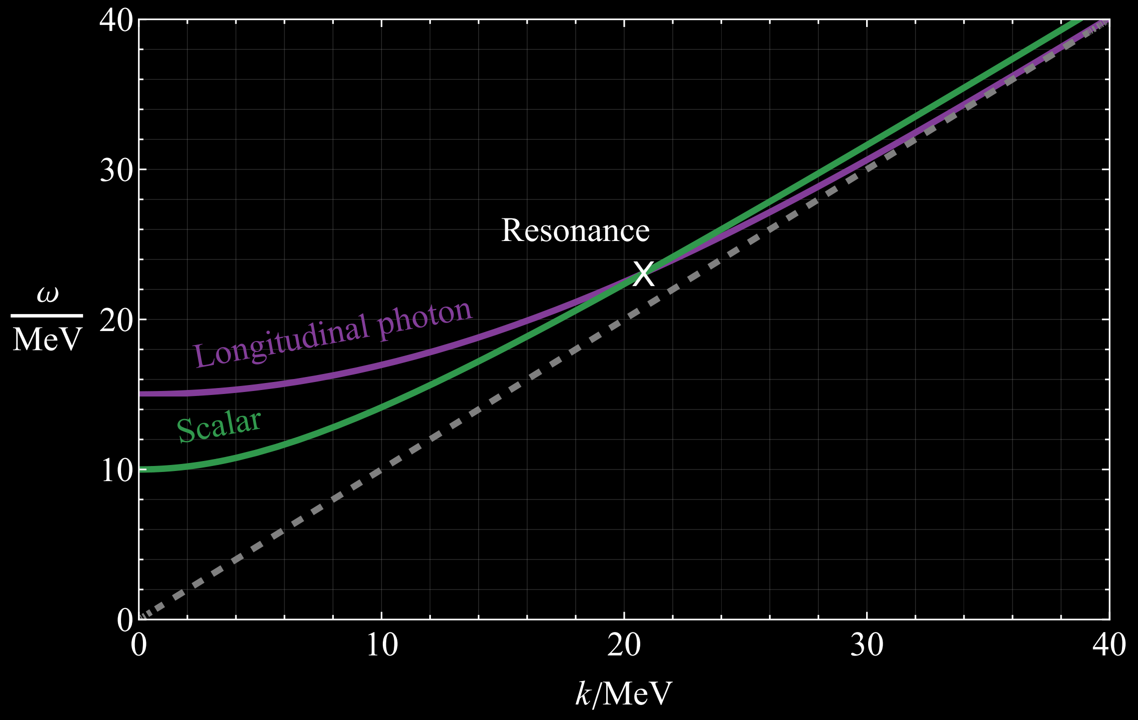
Electromagnetic processes



EM process $\Longrightarrow$ weak coupling

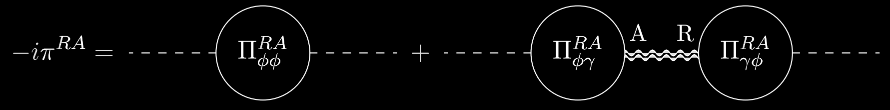
BUT: plasmon and scalar can mix
$\Longrightarrow$ **resonant** enhancement
becomes possible

RESONANT PRODUCTION



- Use real-time TFT formalism in RA-basis

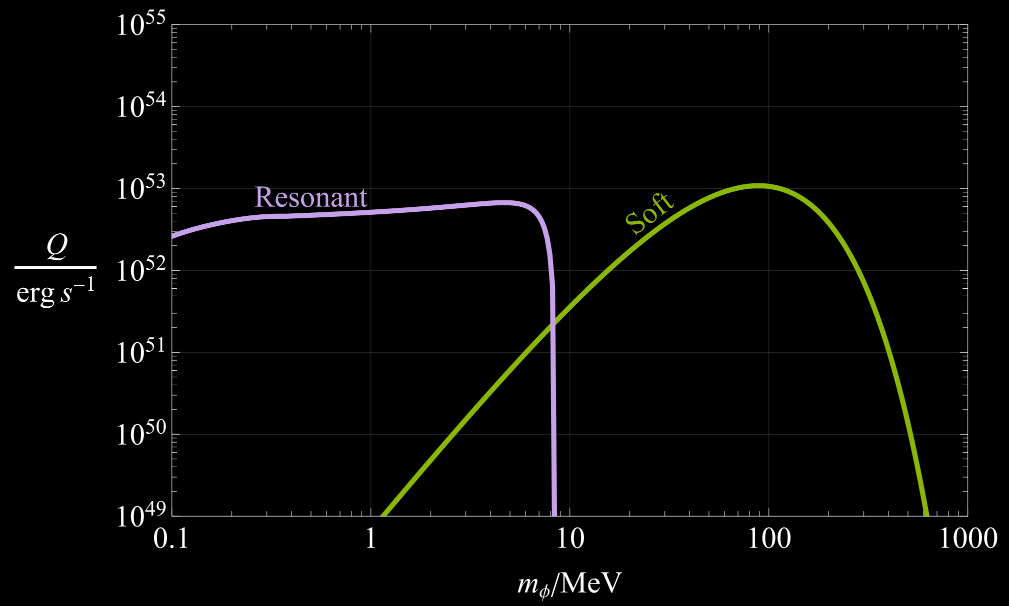
$$\Gamma_{\text{prod}}(\omega) = -\frac{\text{Im}[\pi^{RA}(\omega)]}{\omega\left(e^{\omega/T}-1\right)}$$

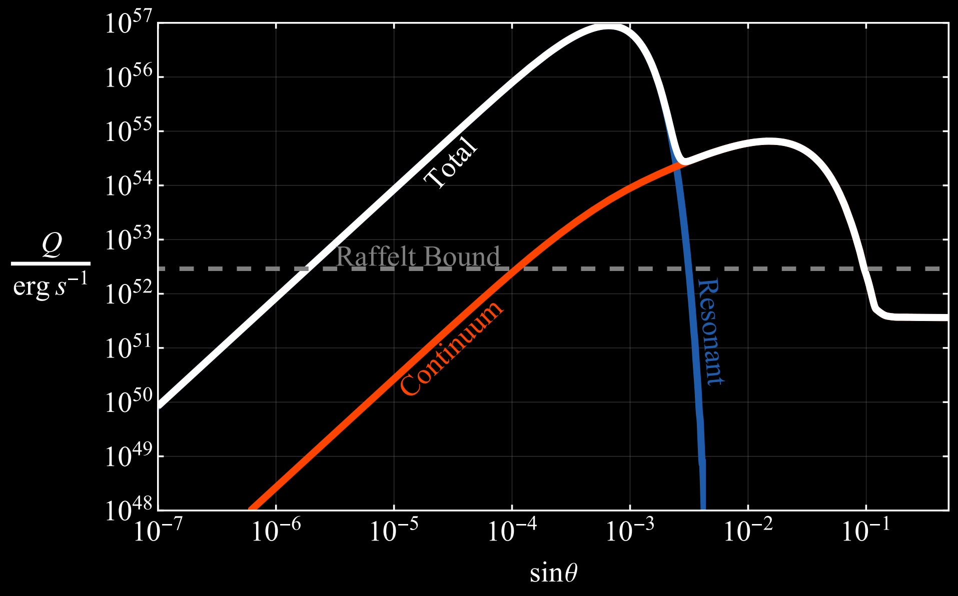


- Resonant part: $$\text{Im}[\pi^{RA}(\omega)] = -\text{Im}\left[\frac{(\Pi^{RA}_{\phi L})^2}{\Pi^{RA}_L - m_\phi^2}\right] = -\left(\frac{\omega}{m_\phi}\text{Re}[\Pi^{RA}_{\phi L}]\right)^2 \frac{\sigma_L \omega}{(\sigma_L\omega)^2 + (\omega^2-\omega_L^2)^2}$$

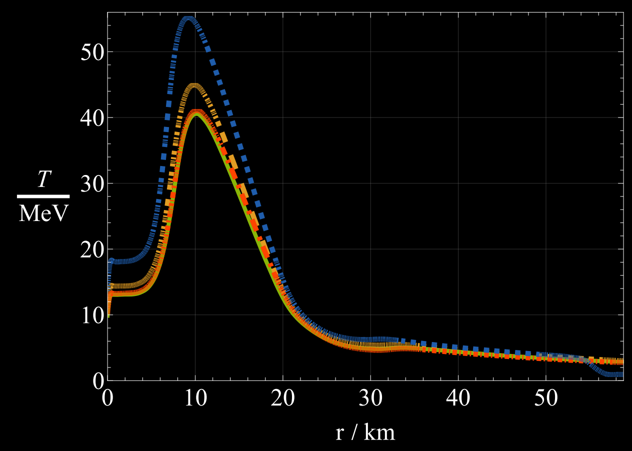
- Resonance occurs whenever PLASMA FREQUENCY > MASS(ϕ)

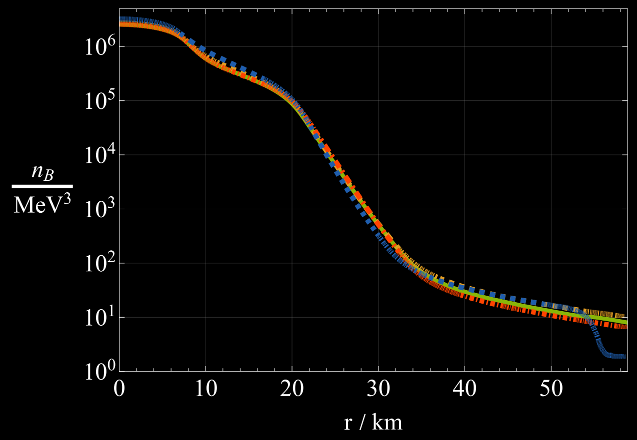
REGIMES OF EMISSION





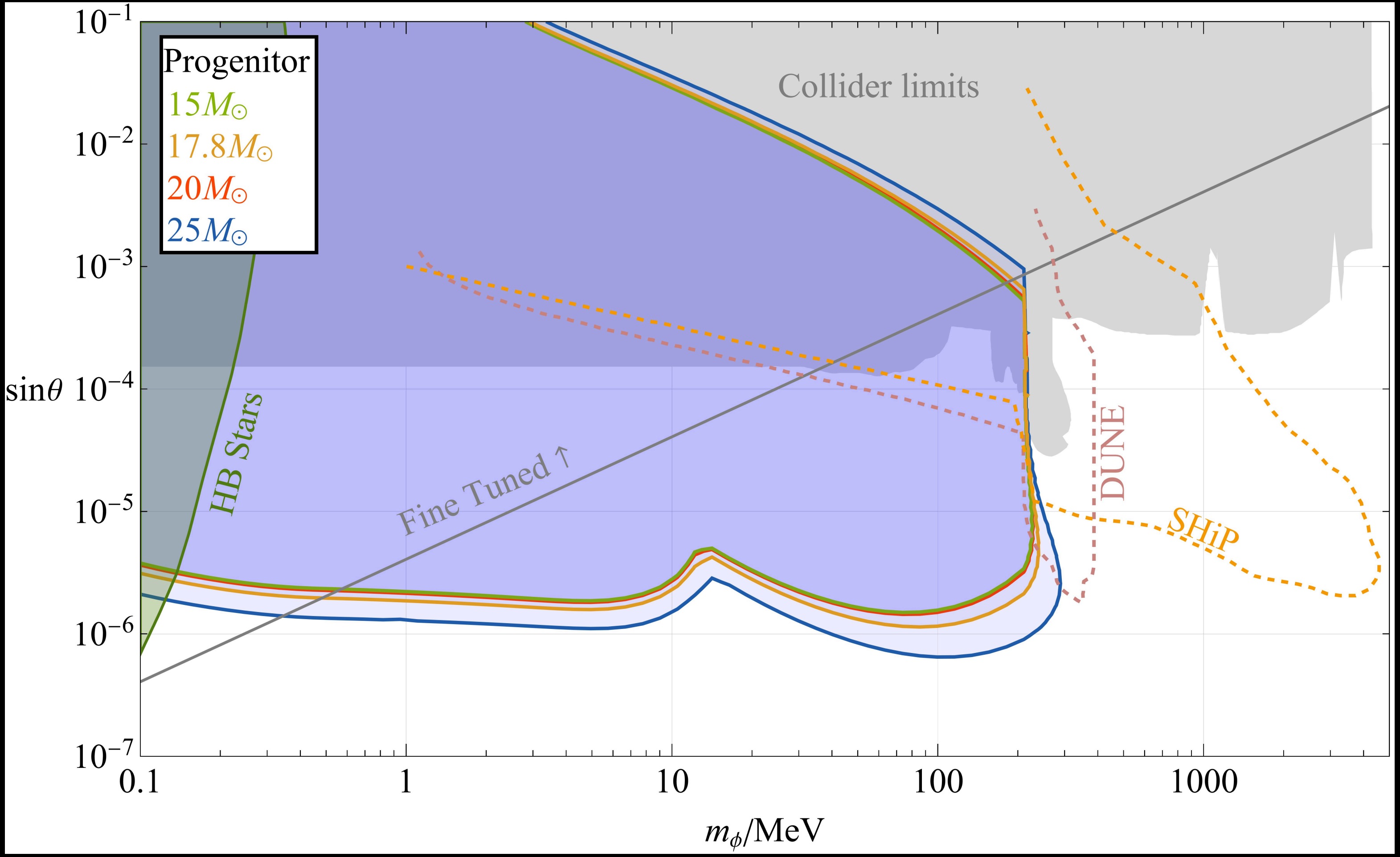
ASTROPHYSICS INPUT





- Use observed neutrino signal from SN 1987A to probe scalars
- Reference model for SN 1987A: 1d neutrino-driven explosion
- Use simulation data for the end of the accretion phase
- Use 4 different progenitors to estimate uncertainties

RESULTS



Progenitor
$15M_\odot$
$17.8M_\odot$
$20M_\odot$
$25M_\odot$
Collider limits
HB Stars
Fine Tuned ↑
DUNE
SHiP
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
$\sin\theta$
0.1
1
10
100
1000
m_ϕ/MeV