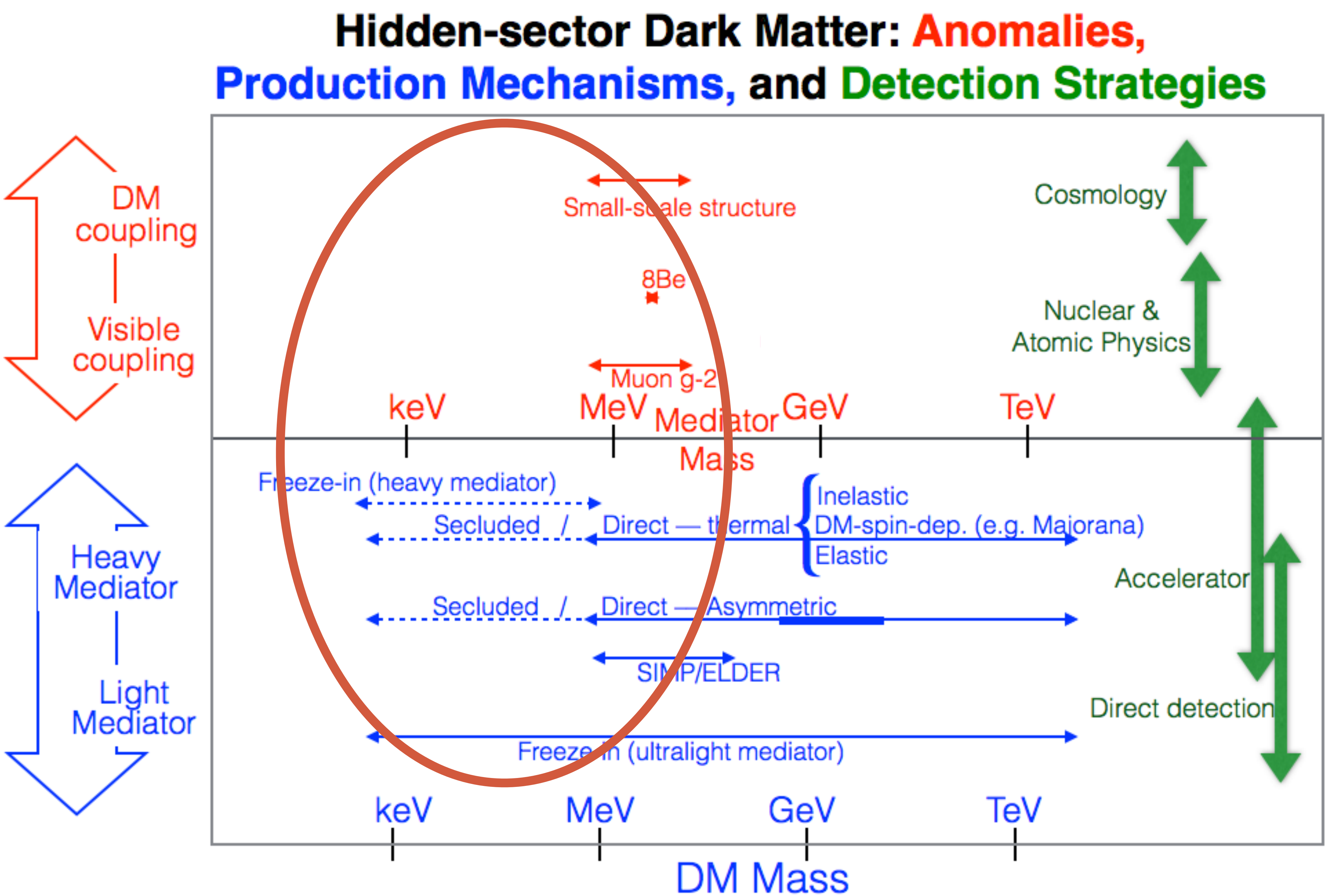
THE GAMMA FROM NUCLEAR DECAYS HIDING FROM INVESTIGATORS (GANDHI) EXPERIMENT

Harikrishnan Ramani
BCTP, Berkeley

GANDHI- arxiv:1810.06467

with Giovanni Benato, Alexey Drobizhev, Surjeet Rajendran

DARK FORCES LANDSCAPE



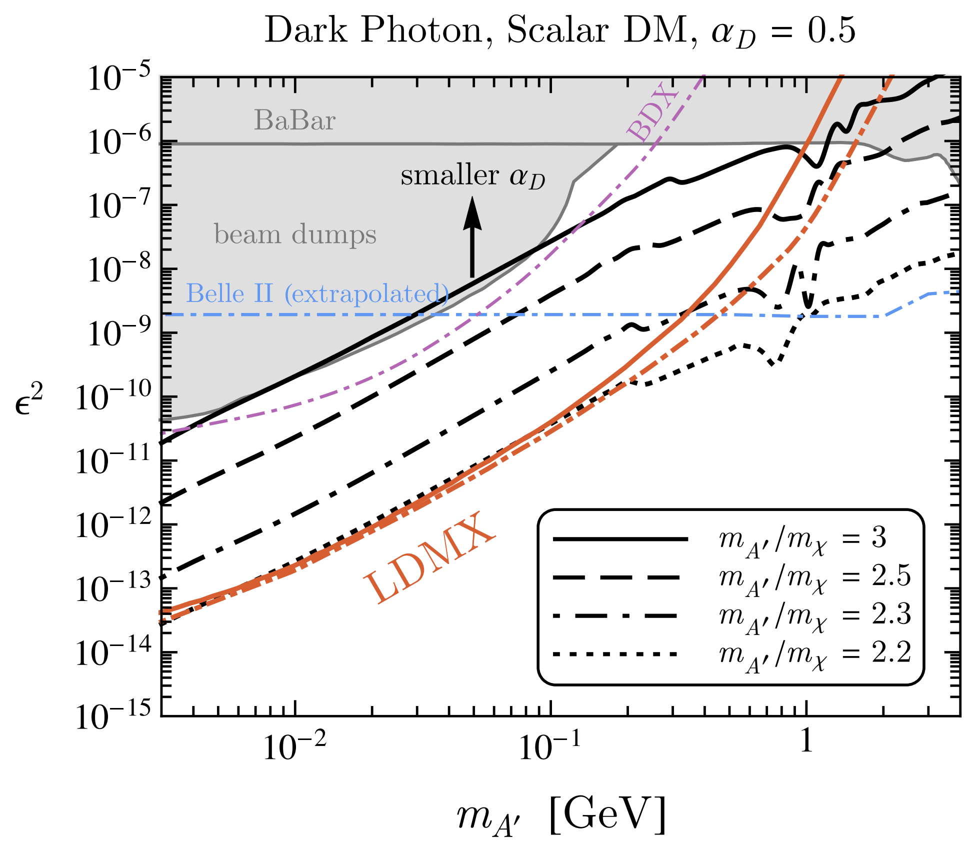
Cosmic Visions : 2017

LIGHT DARK BOSONS

- Help shockwaves trigger Type II supernovae
- Relaxion models
- Dark matter
- Or mediate light DM - SM interactions
- Light DM Direct Detection, mediator cannot be too heavy; x-section drops precipitously.
- Opportunity to constrain the mediator itself.

LIGHT DARK FORCES - STATUS

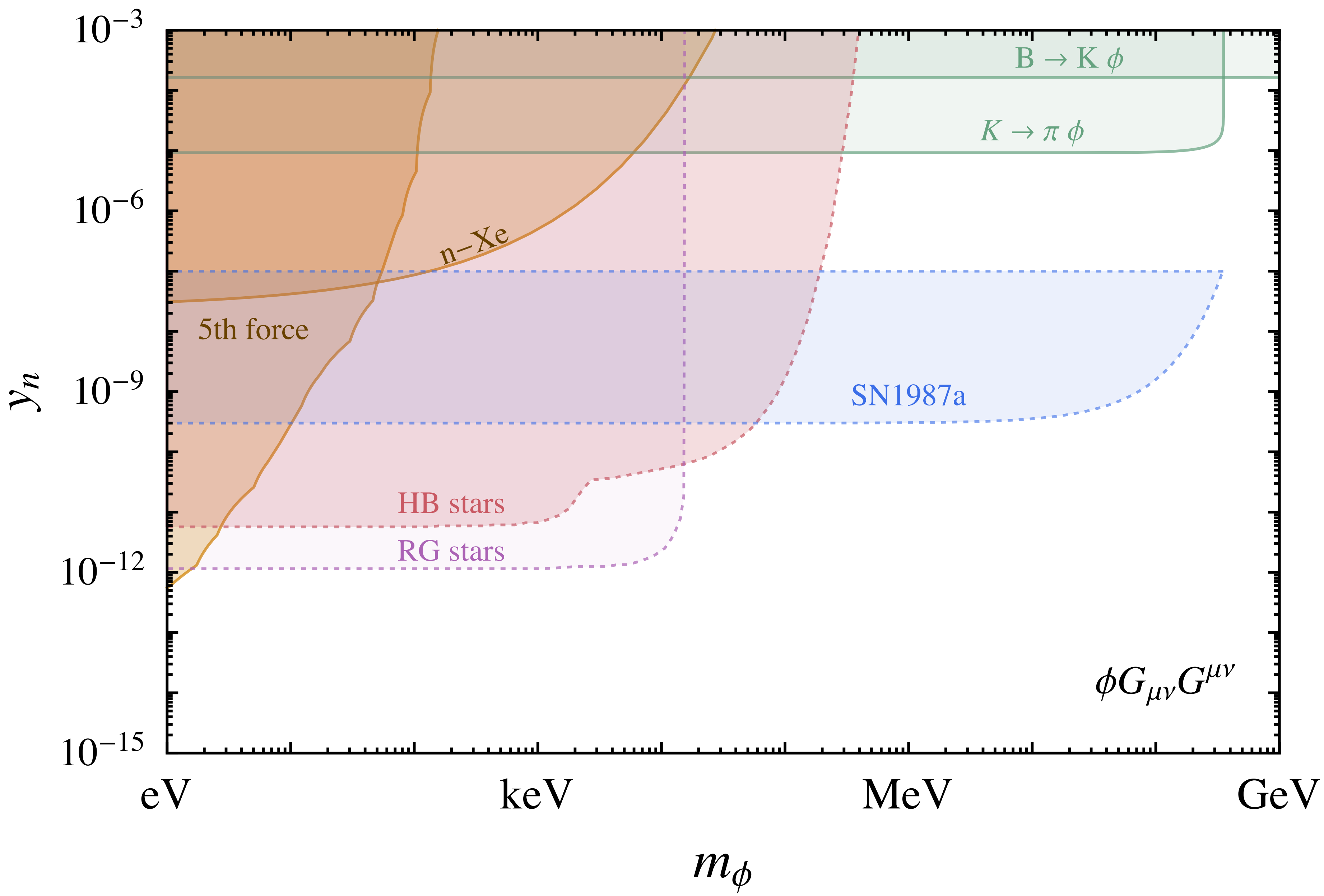
- NA64, BDX, LDMX etc are proposed to look for forces coupled to electrons



Source:LDMX

- Nucleophilic forces are harder to constrain.

STATUS OF NUCLEOPHILIC FORCES - SCALAR MODEL



Source:1709.07882, Knapen, Lin, Zurek

**one degree of freedom is in 2 sigma tension with BBN*

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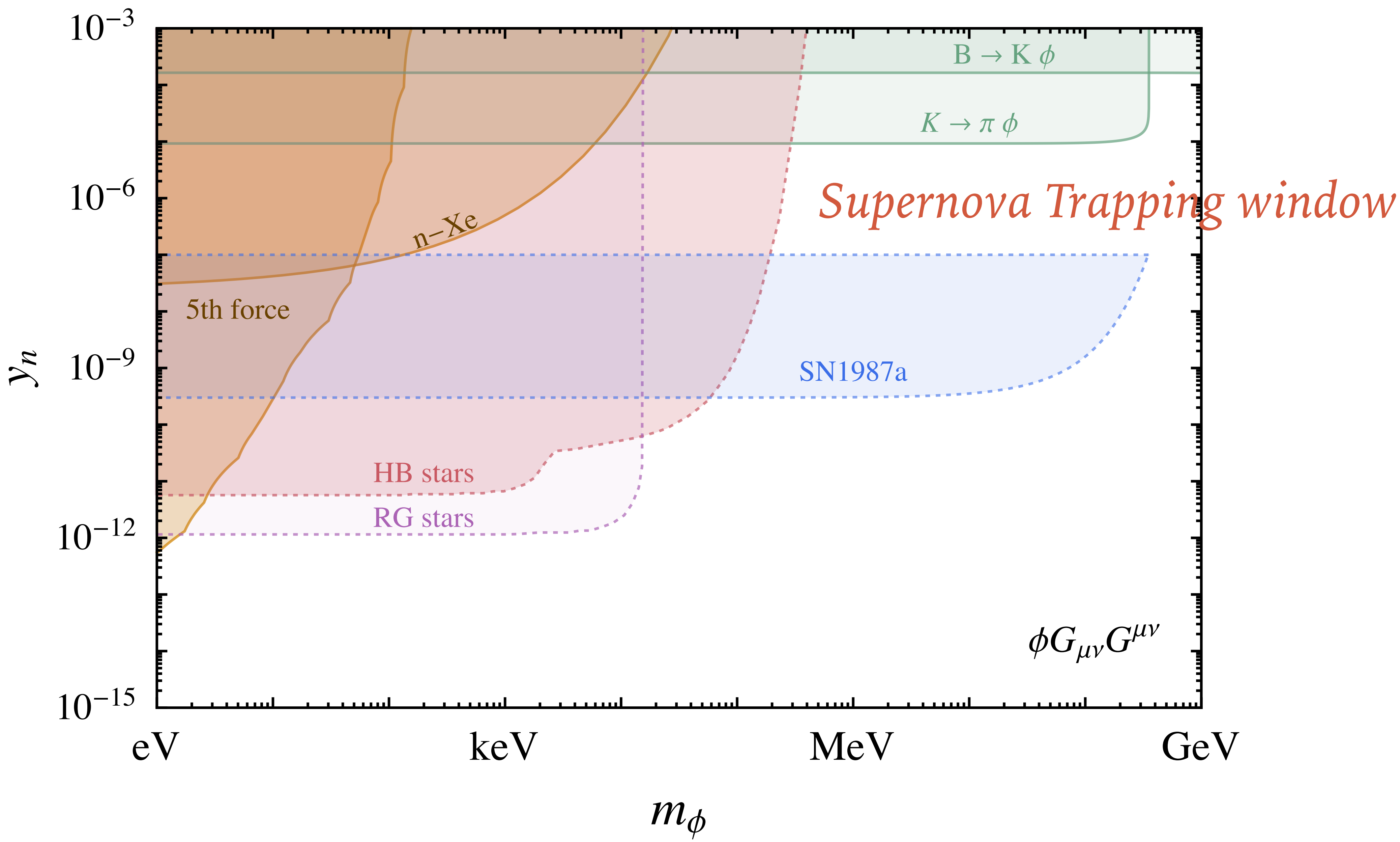

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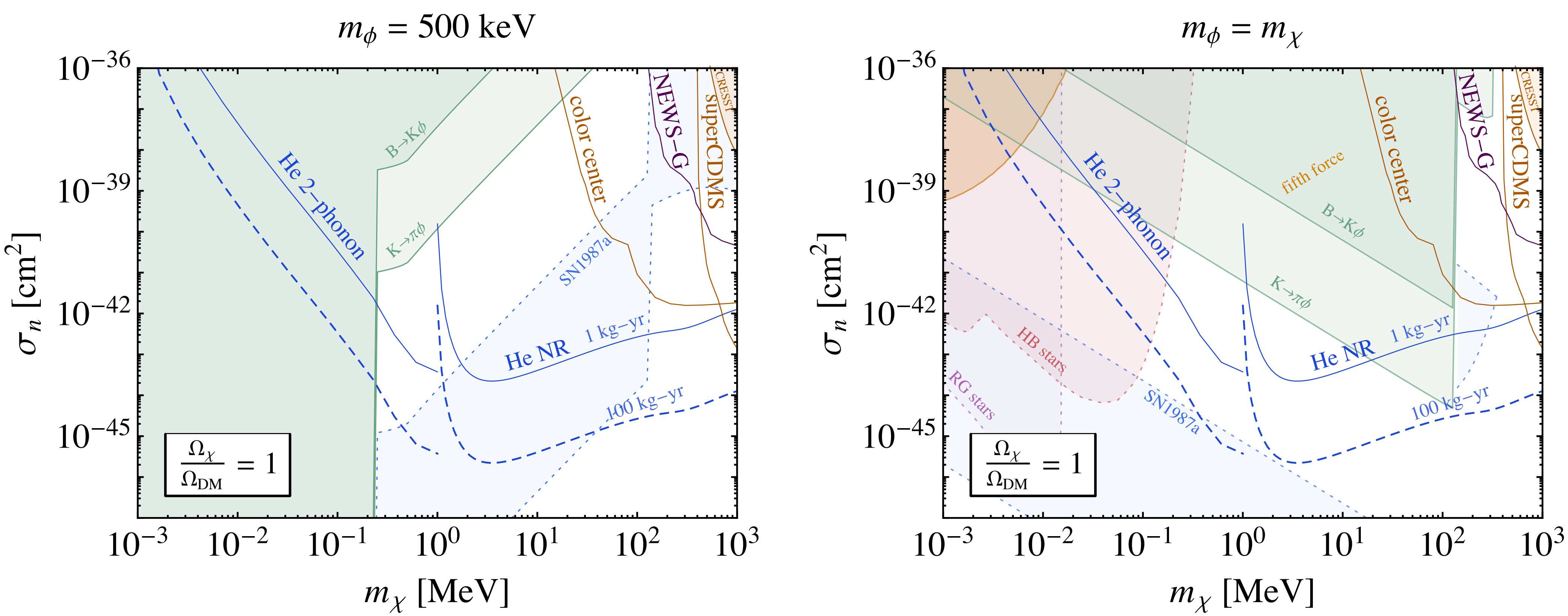
LOOPHOLES TO BUILD DM MODELS…

$$\mathcal{L} \supset -\frac{1}{2}m_\chi^2\chi^2 - \frac{1}{2}m_\phi^2\phi^2 - \frac{1}{2}y_\chi m_\chi \phi\chi^2 - y_n\phi\bar{n}n$$



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For direct probes of this parameter space: Rouven's talk

COULD WE DO BETTER?

MET

- missing energy experiments stay agnostic to decay modes
- furthermore, pay small factor only once
- how do we do this for a baryonic force? doing MET search for baryons is a messy enterprise.

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- (Missing) Gamma Decays

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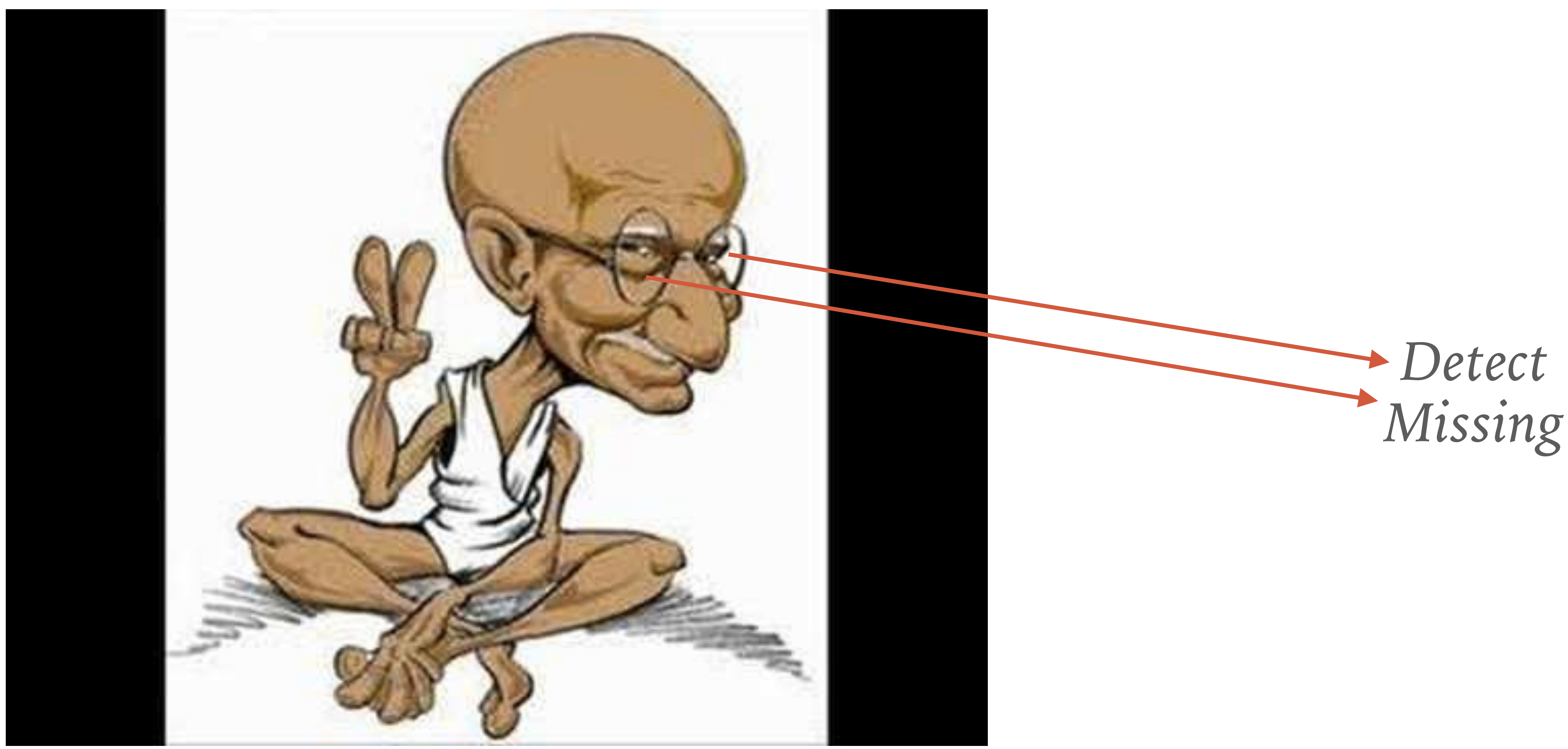
NUCLEAR PHYSICS FOR PEACE



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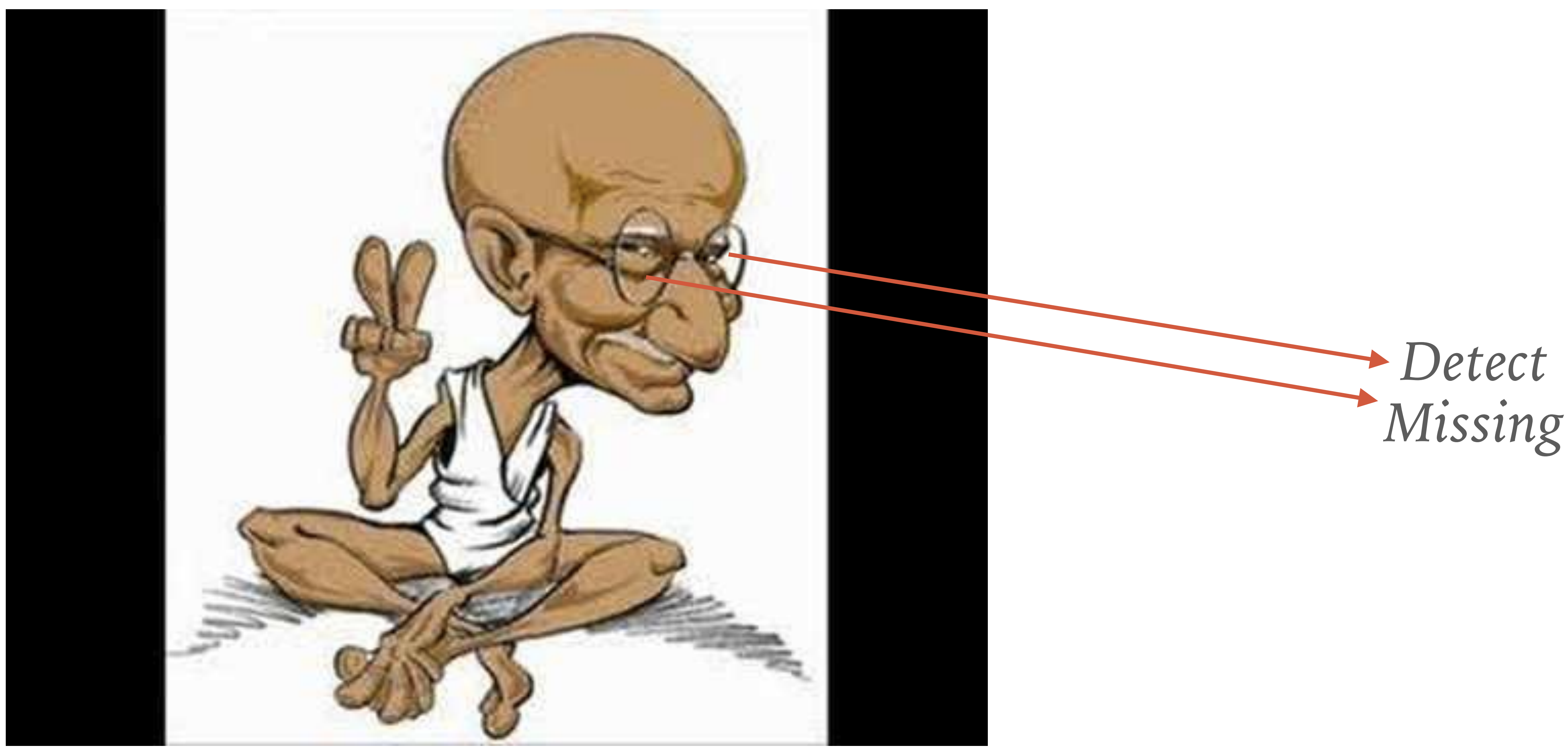


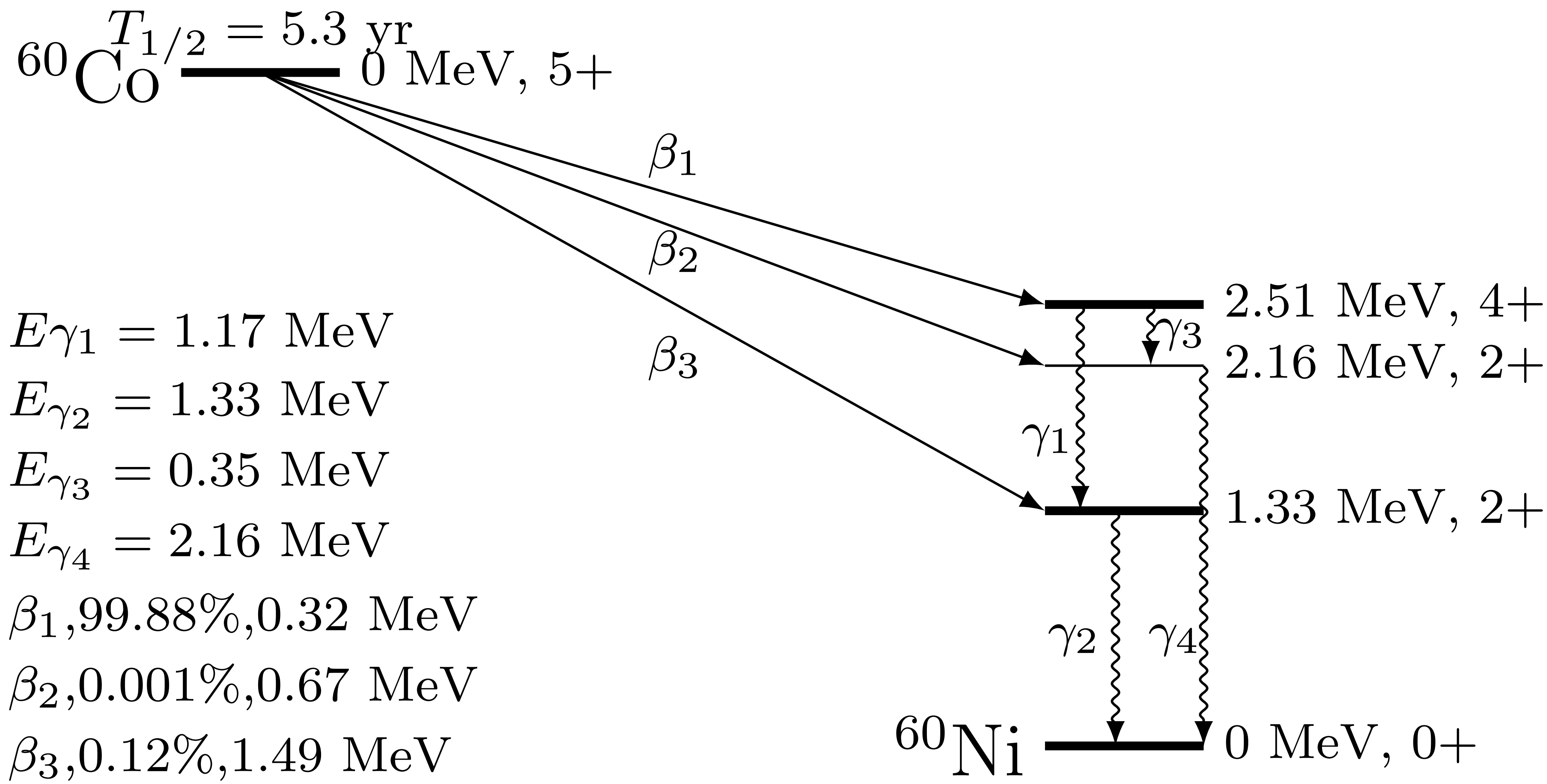
WHAT IS THE LARGE NUMBER?

- Need for large statistics. typically EOT in a beam-type exp.
- Avogadro number of decaying nuclei is a naturally large number
- Can we do nuclear gamma decays and look for MET?

ISOTOPE SELECTION

- Isotopes which are long-lived, high energy gamma emitters.
- Decay sequence that is trigger-able
- Industrial production is a plus.
- Candidates: ^{60}Co, ^{24}Na, ^{65}Ni.

CASCADE GAMMA DECAYS IN COBALT DECAYS



Cascades happen because it is easier to shed two units of spin at a time rather than shedding 4 all at once.

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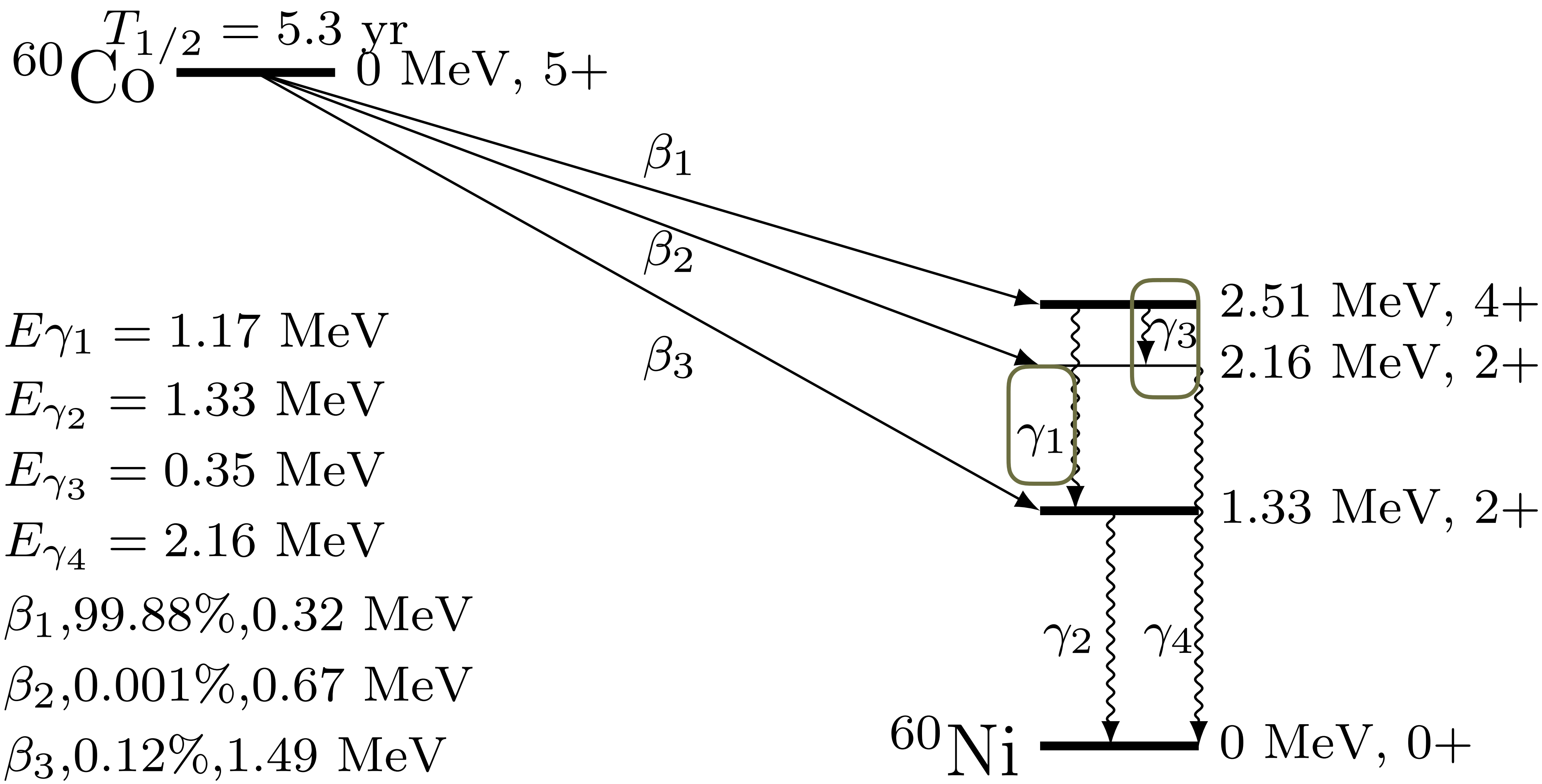

$E\gamma_1 = 1.17$ MeV

$E_{\gamma_2} = 1.33$ MeV

$E_{\gamma_3} = 0.35$ MeV

$E_{\gamma_4} = 2.16$ MeV

β_1,99.88%,0.32 MeV

β_2,0.001%,0.67 MeV

β_3,0.12%,1.49 MeV

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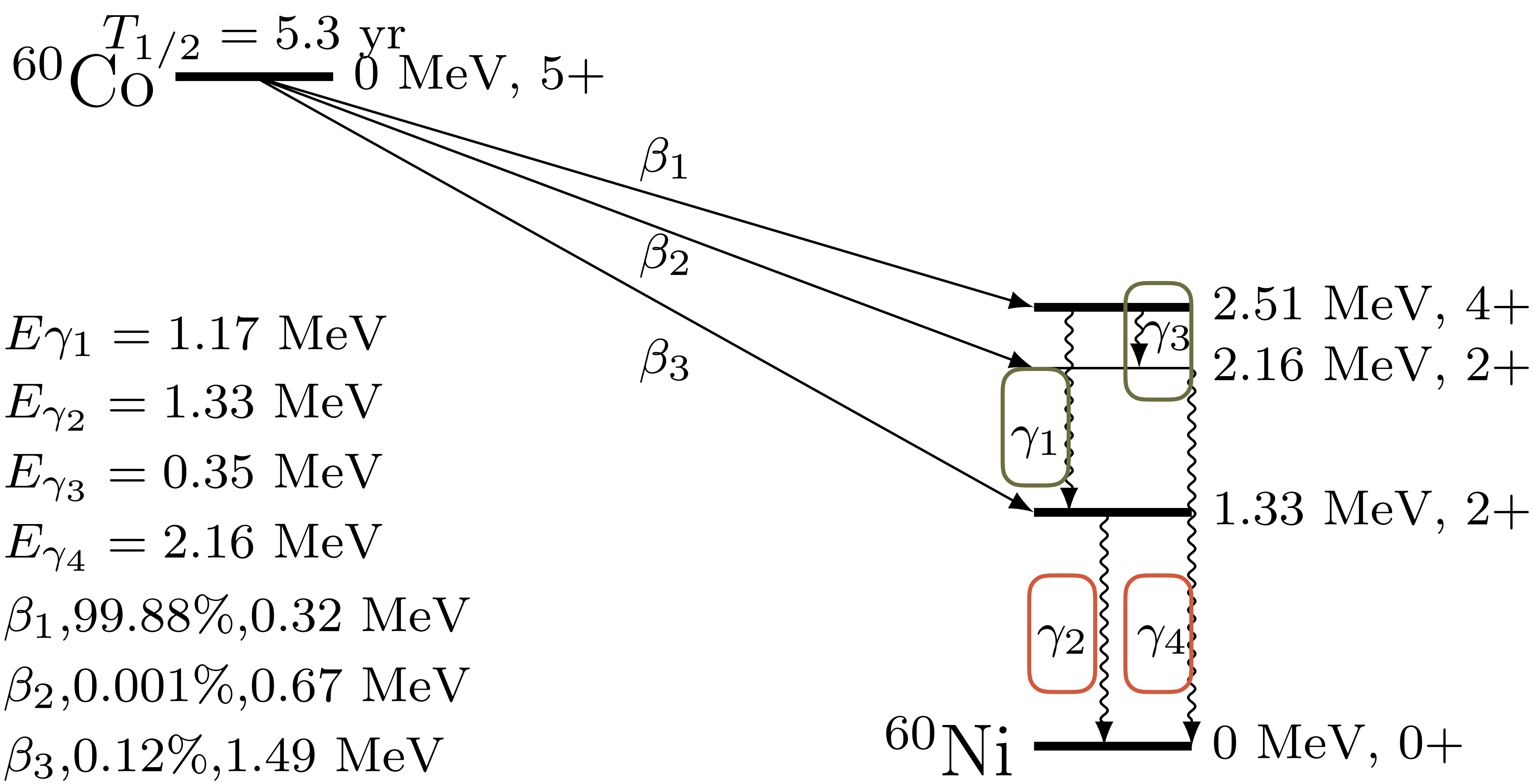

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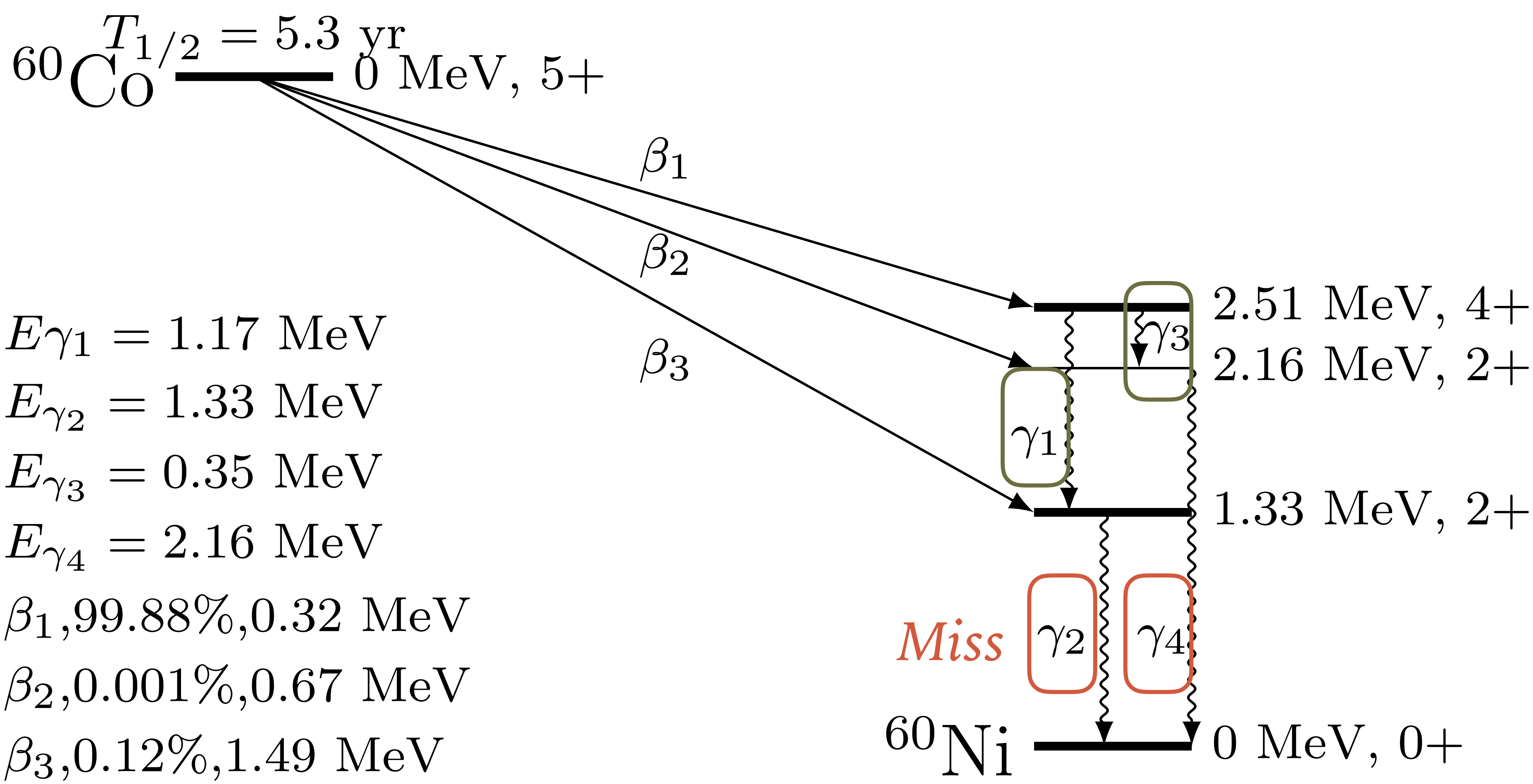

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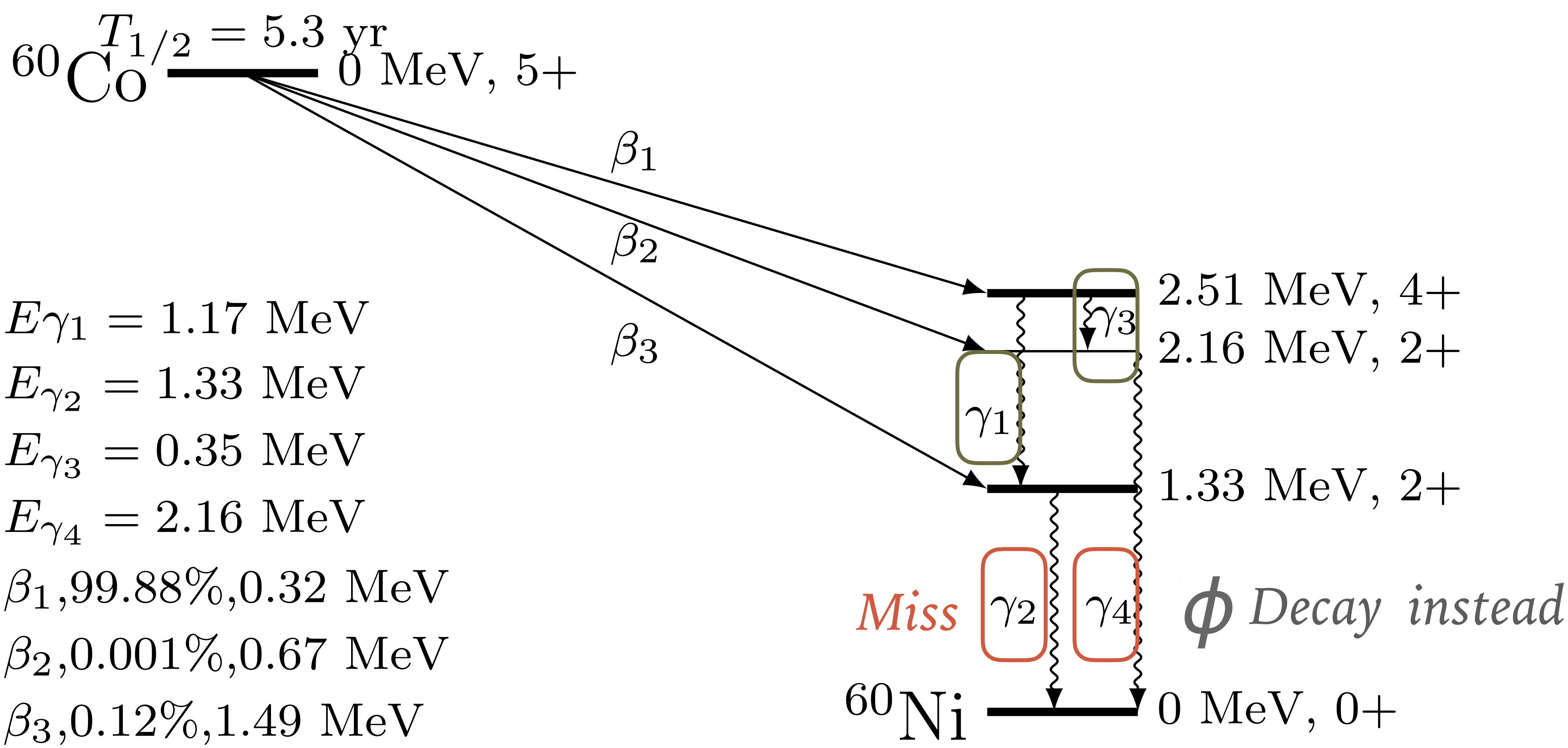

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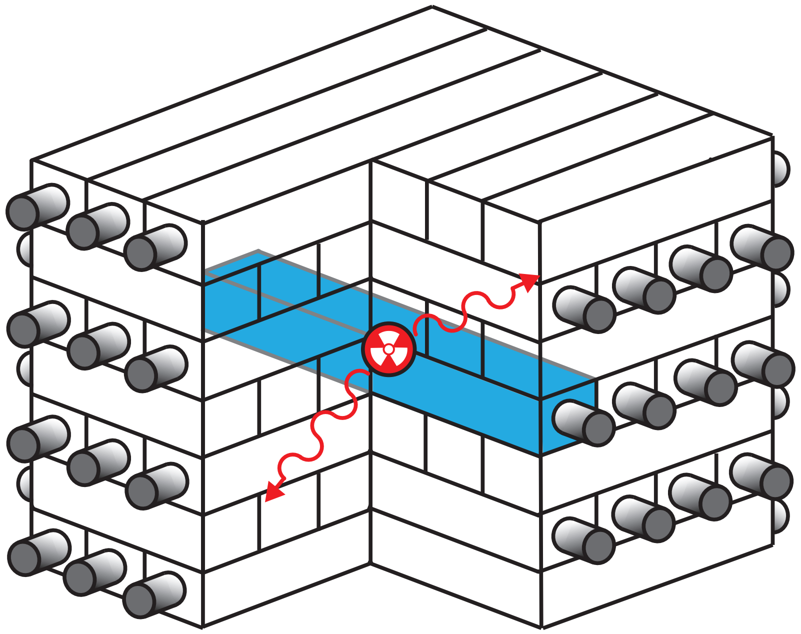
SIGNAL

- Cobalt foil inside a hermetically sealed detector
- Trigger on beta+first gamma
- Signal event is a beta+first gamma+missing subsequent second gamma

PHOTON DETECTION - SCINTILLATORS

- Photon detection with minimum dead-time
- Energy resolution, very important.
- Intrinsic Radioactivity needs to be kept low
- Large detector volumes for containment
- Plastic Scintillators are ideal choice - BC-404
- Large stack of crystal scintillators works too
- A Hybrid solid scintillator core + liquid scintillator body might work also. Borexino?
- Minimal dead regions/cracks, hermeticity.

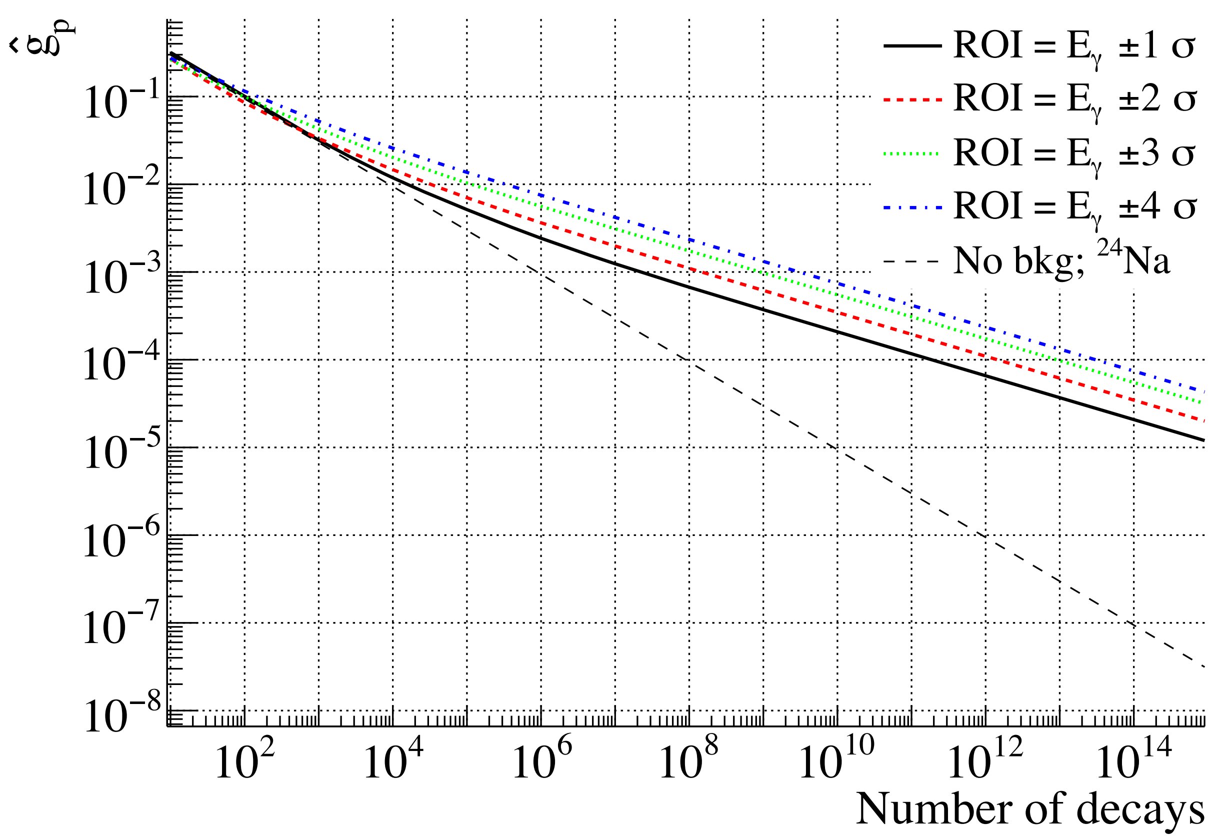
DETECTOR SCHEME

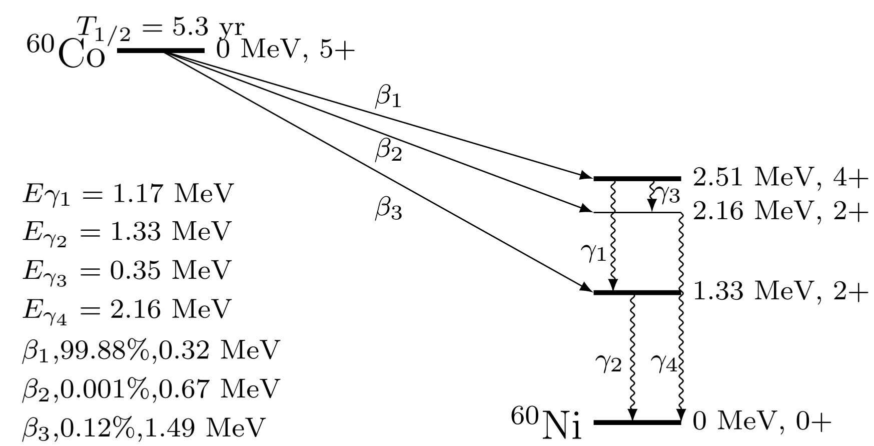


- Hermetic Detector divided into 3 modules
- Central modules to completely stop betas ~ cm
- Inner module to detect majority of the gammas ~ 10cm. Require detection of first gamma here
- Outer module depending on the efficiency required.

1.33 MEV GAMMA MIMICKING 1.17 MEV GAMMA

Mixing angle





- As statistics increase, need tighter cuts to differentiate tails
- Soft Compton could also cause similar background
- Dead Regions: typical size too small to cause similar effect
- Happens mainly because $E_2 > E_1$
- ^{24}Na does not suffer from this….

RADIOGENICS

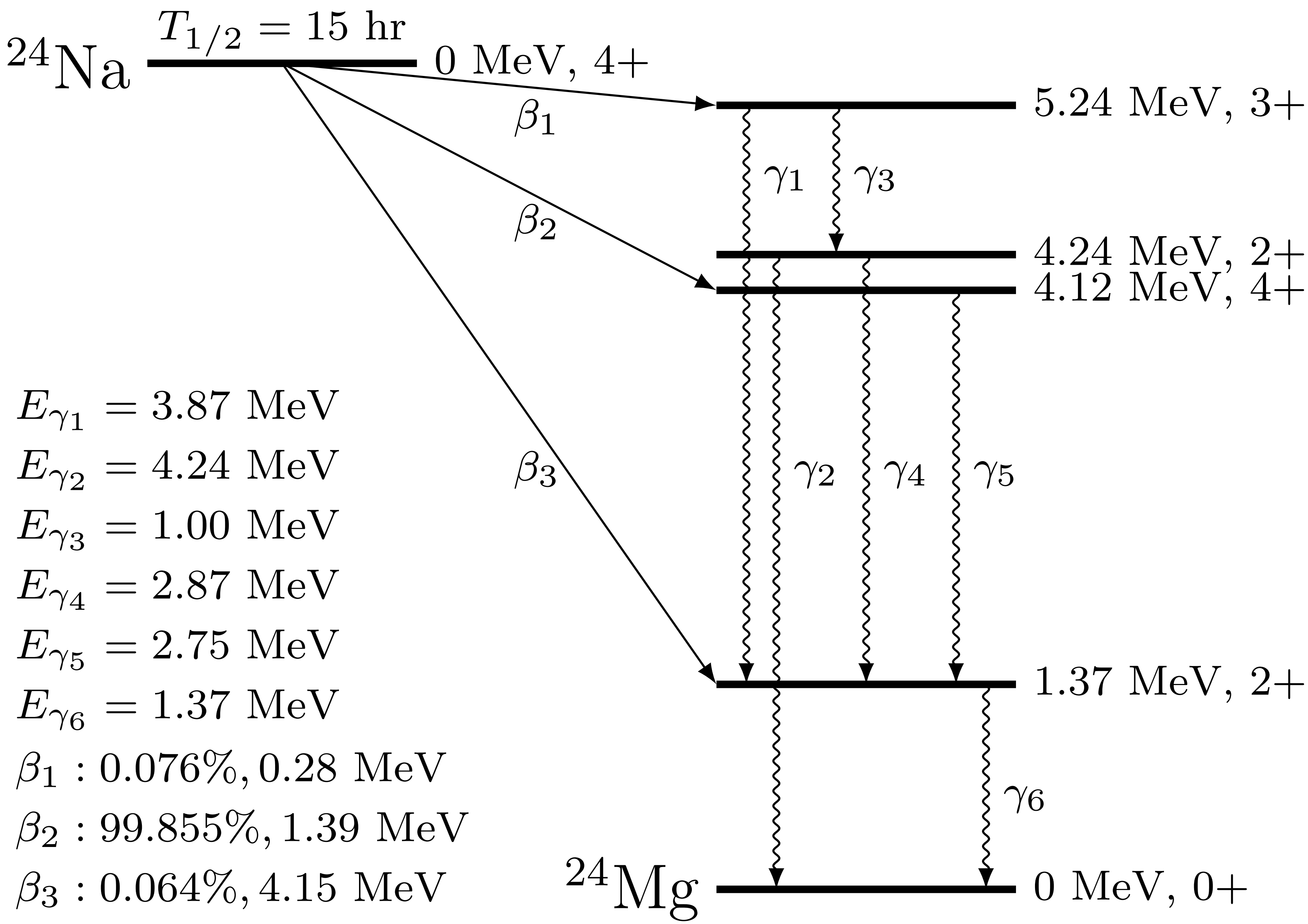
- For ^{60}Co, dominant background from ^{40}K contaminant
- Occurs through EC
- Gamma can soft scatter in central module + rescatter in inner module
- Total run-time dependent, higher event rate ameliorates
- Tighter cuts in beta deposition helps too.

COSMOGENICS

- Cosmic Rays / neutrons scatter first in the outer volumes.
- Requiring central→inner→outer module energy deposition mitigates.
- Neutrinos could cause inelastic scatter + subsequent gamma radiation
- Low for a 1 year run.

^{24}NA

Will need experiment to happen close to source.



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$\beta_1 : 0.076\%, 0.28$ MeV

$\beta_2 : 99.855\%, 1.39$ MeV

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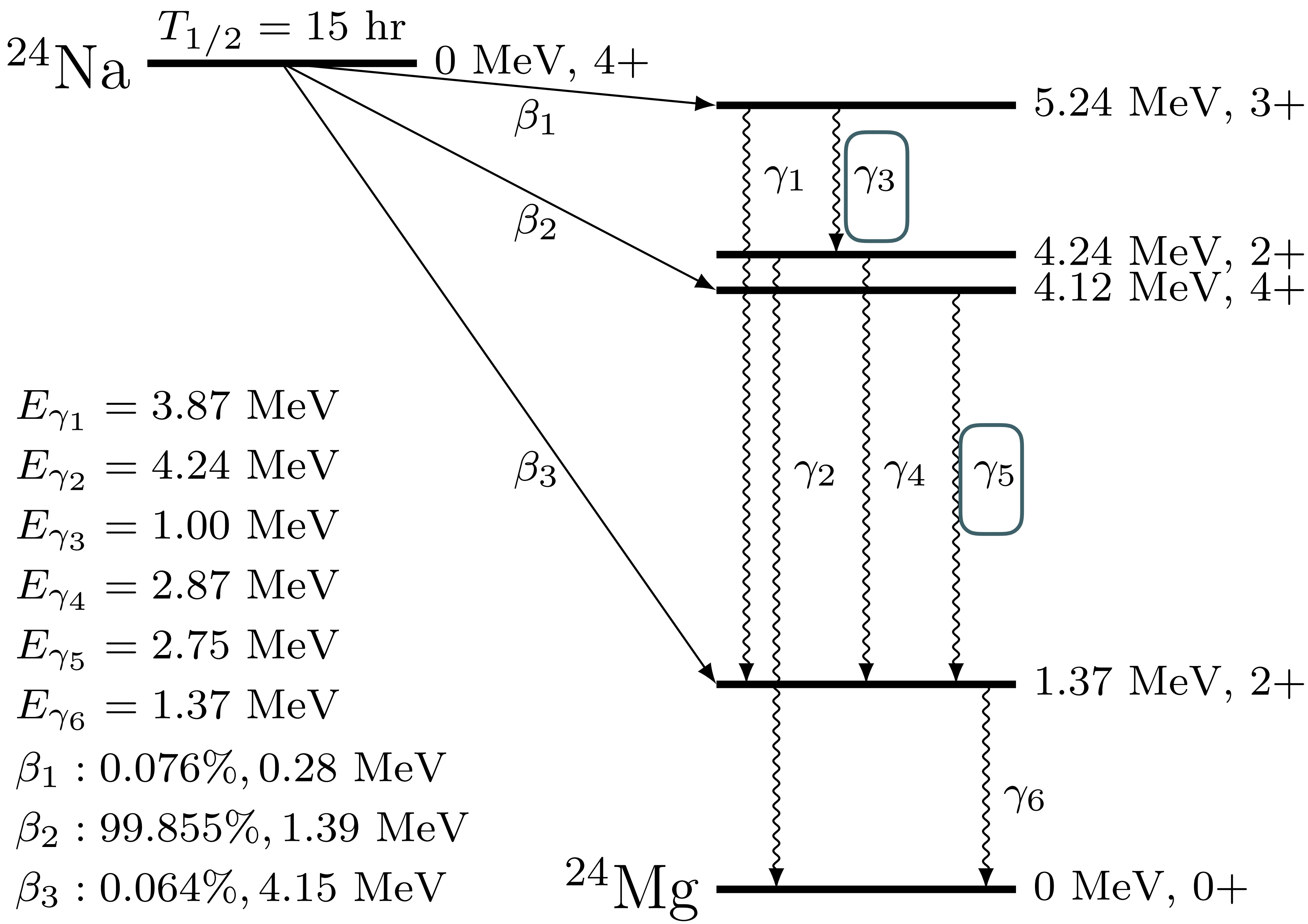

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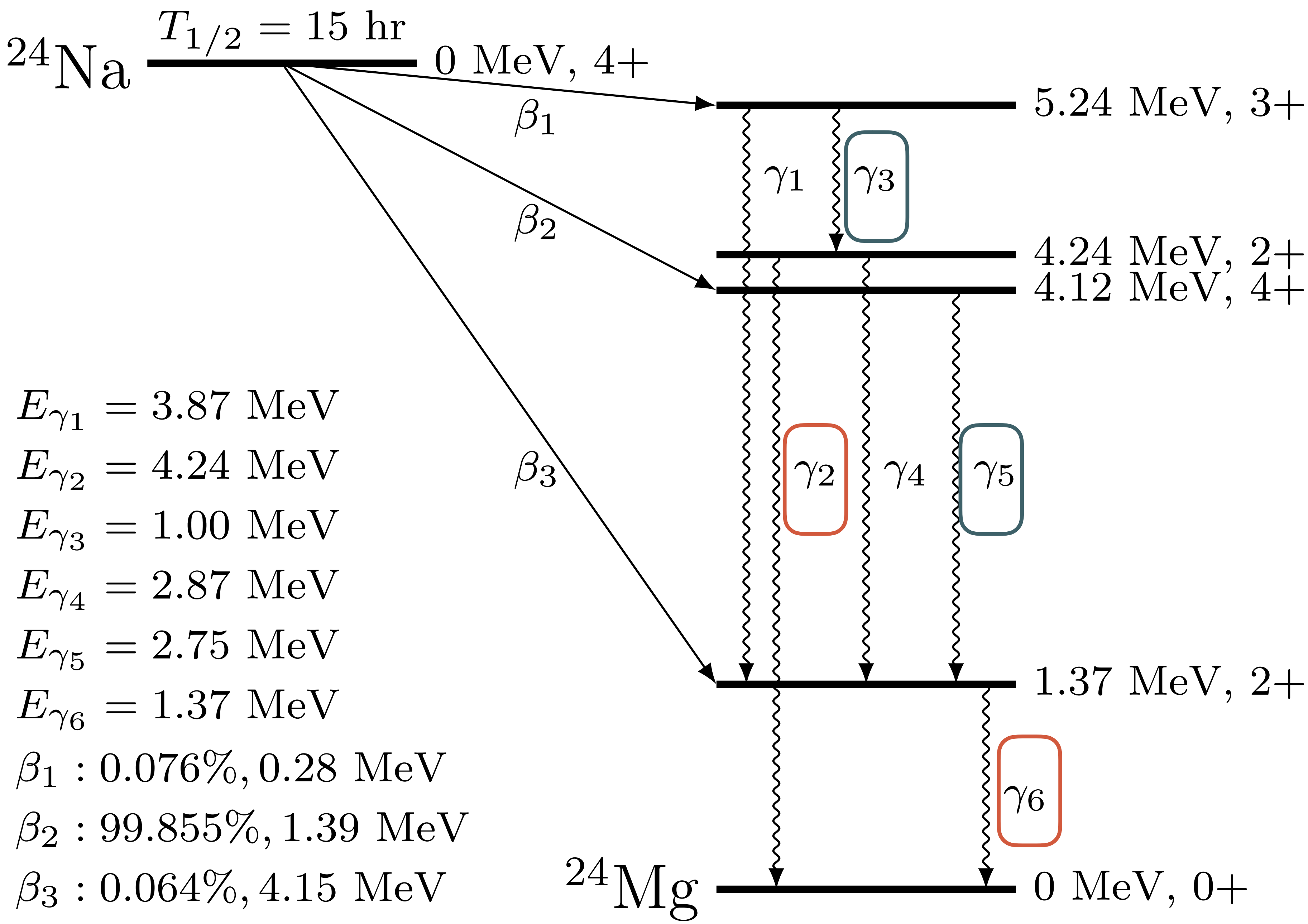

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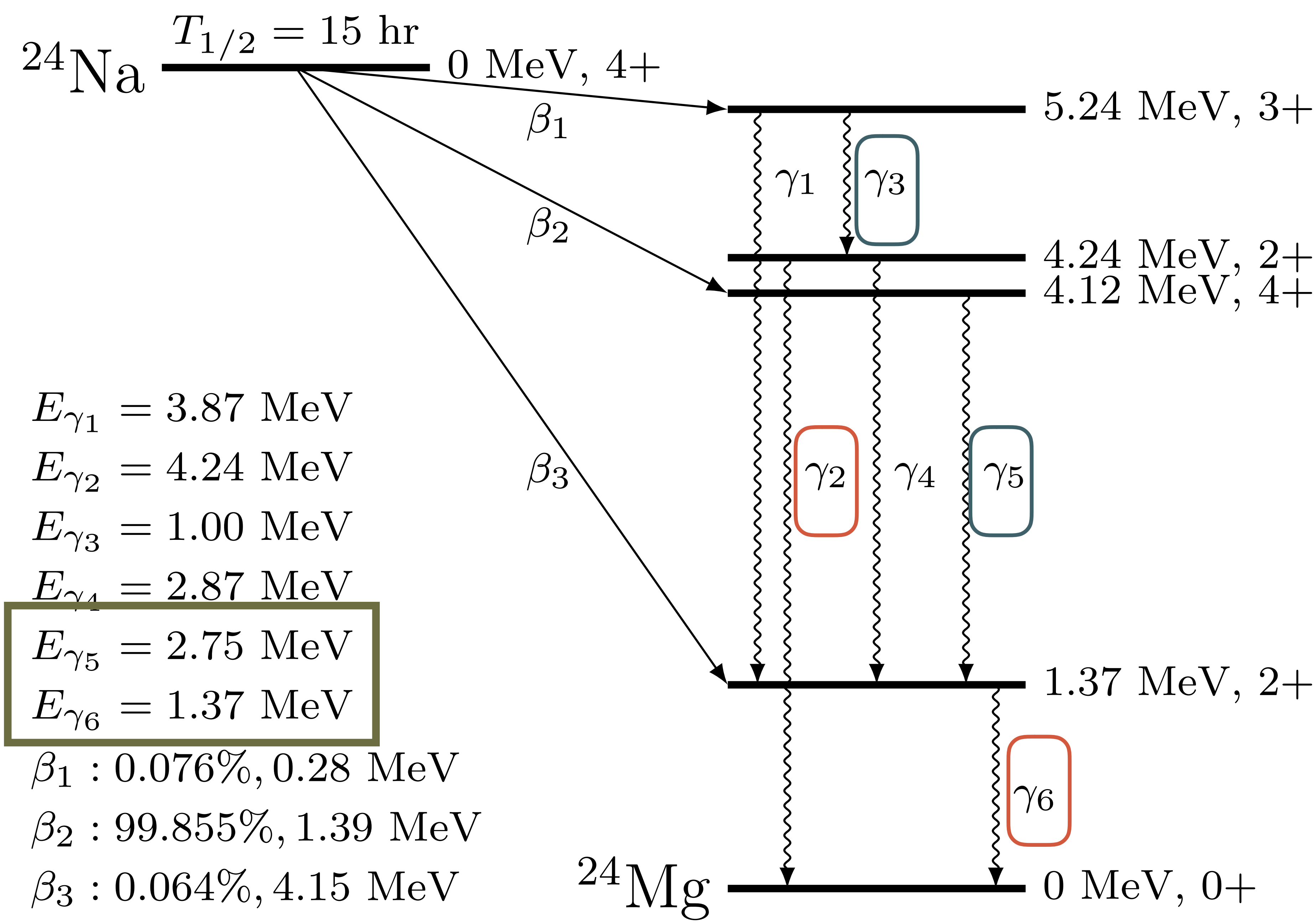

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TOY MODEL

$$\mathcal{L} = g_p \phi \bar{p} p$$

For an E_2 transition,

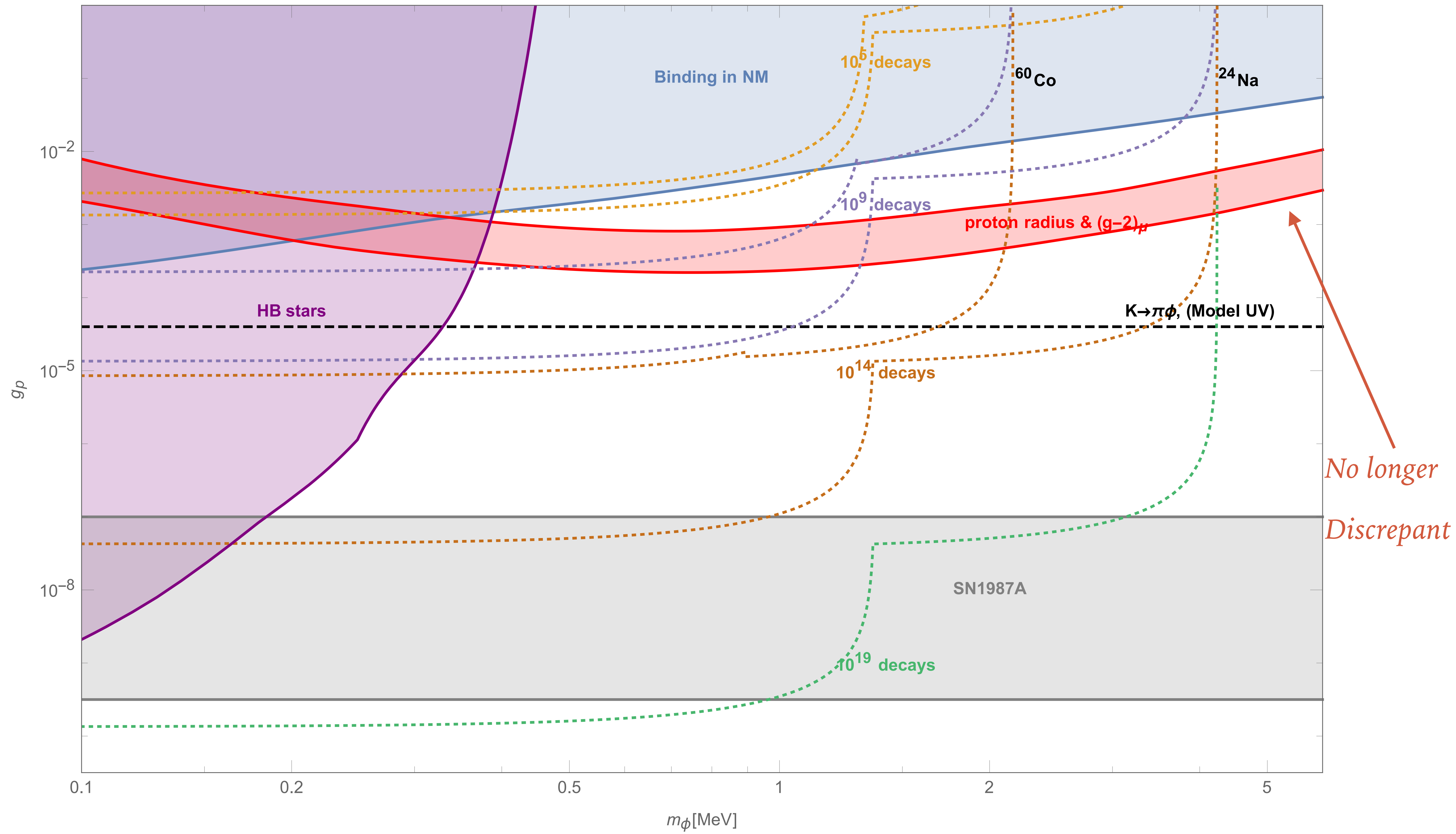
$$H_{\text{int}}^{\phi} = g_p R_p^i R_p^j \nabla_i \nabla_j \phi(k)$$

$$H_{\text{int}}^{\gamma} = e R_p^i R_p^j \nabla_i \epsilon_j$$

Invisible branching fraction:

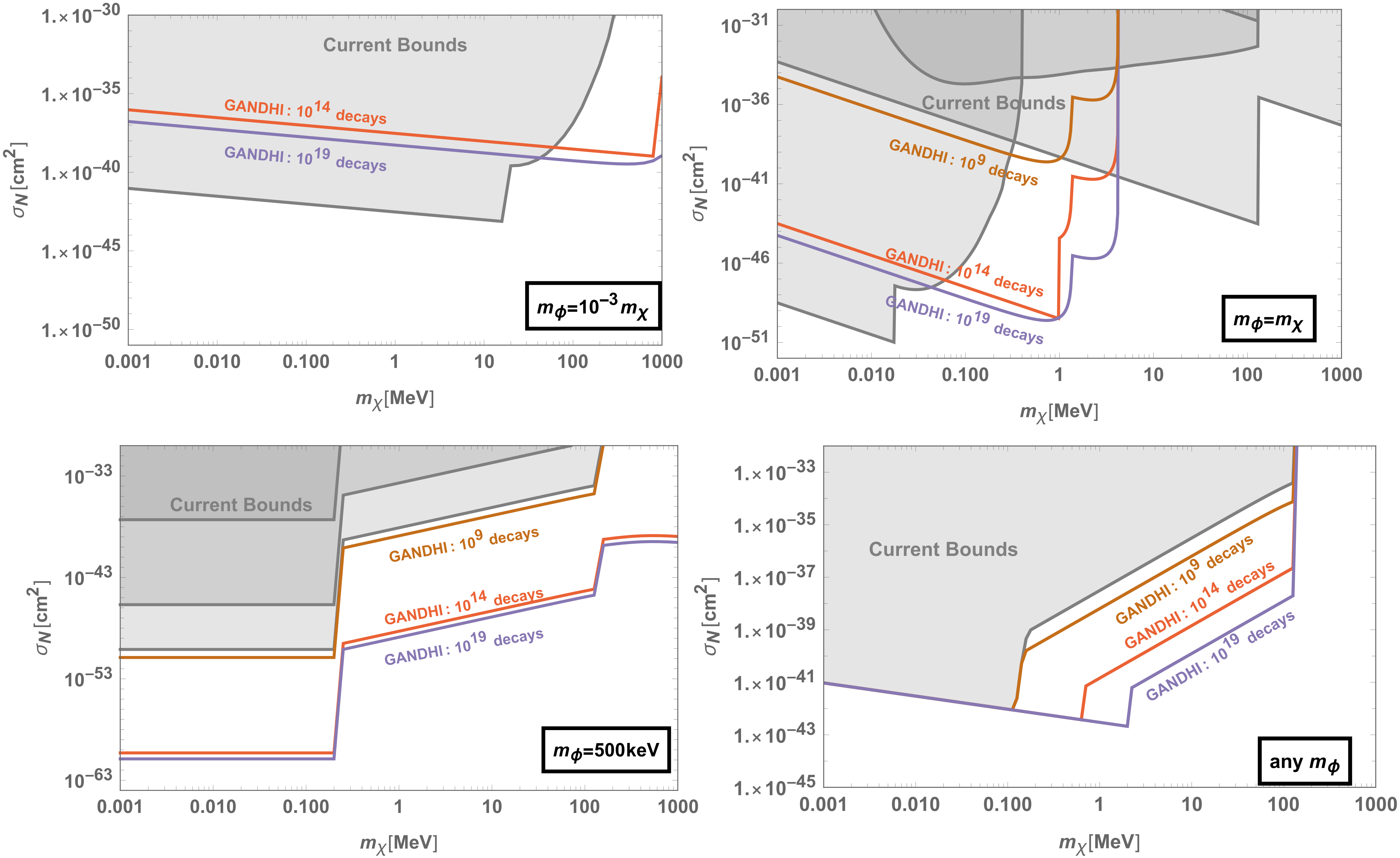
$$\frac{\Gamma(\phi)}{\Gamma_{\gamma,E_2}} \sim \frac{1}{2}\left(\frac{g_p}{e}\right)^2 \left(1 - \frac{m_\phi^2}{\omega^2}\right)^{\frac{5}{2}}$$

REACH

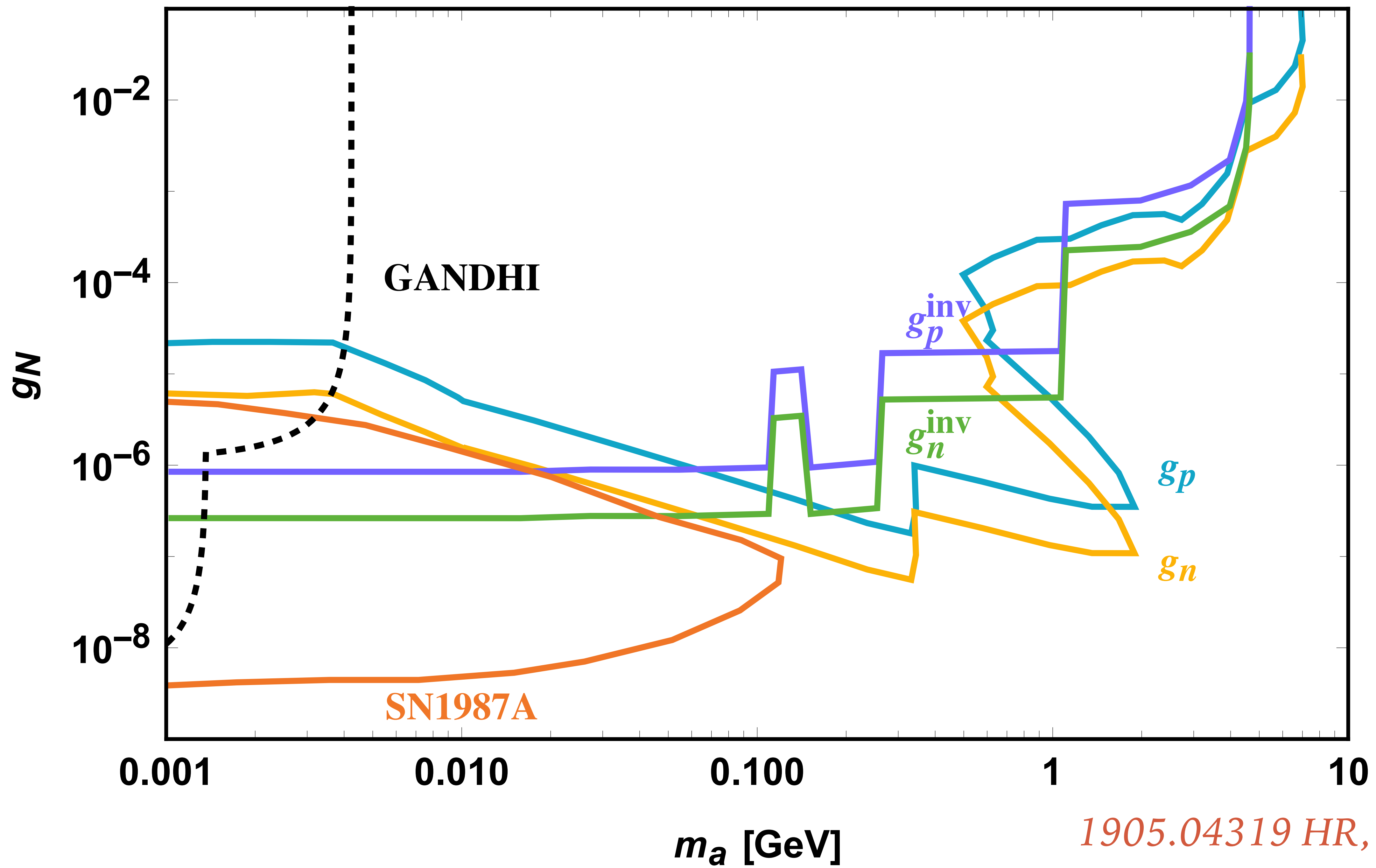


Source for existing limits: Knapen et al. and Y.-S. Liu, D. McKeen, and G. A. Miller ,1605.04612

INDIRECT LIMITS ON LIGHT DARK MATTER MODELS



PSEUDO-SCALAR

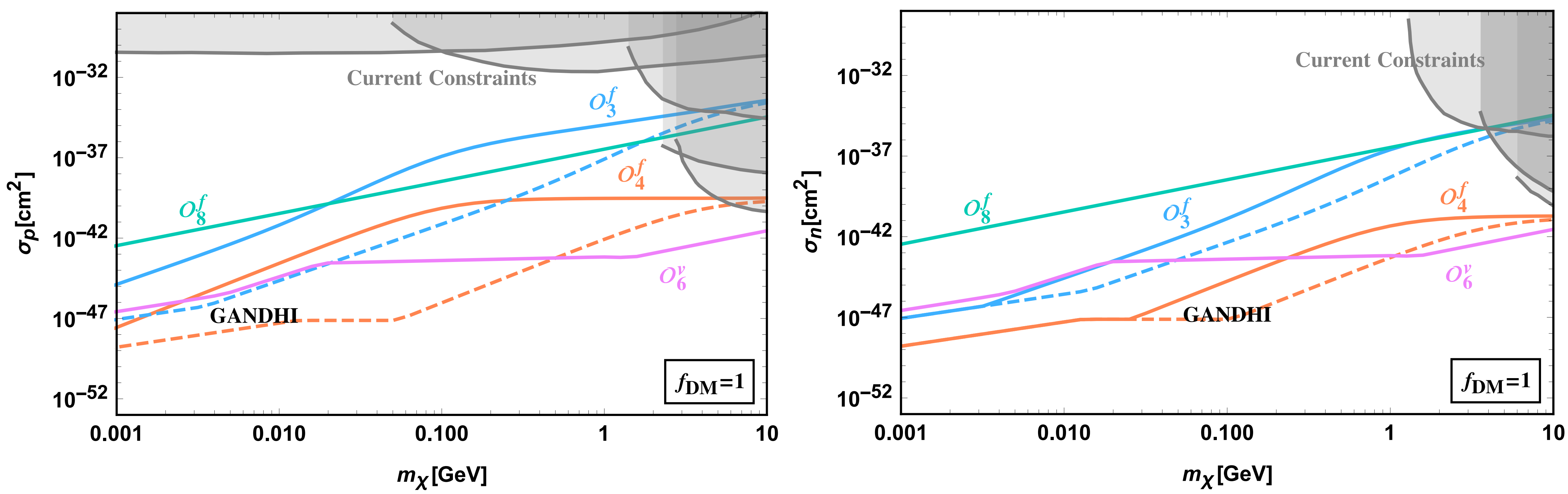


1905.04319 HR, Woolley

- *With 10^{14} decays of ^{24}Na.*
- *Could do better with ^{65}Ni which has M_1 transition*

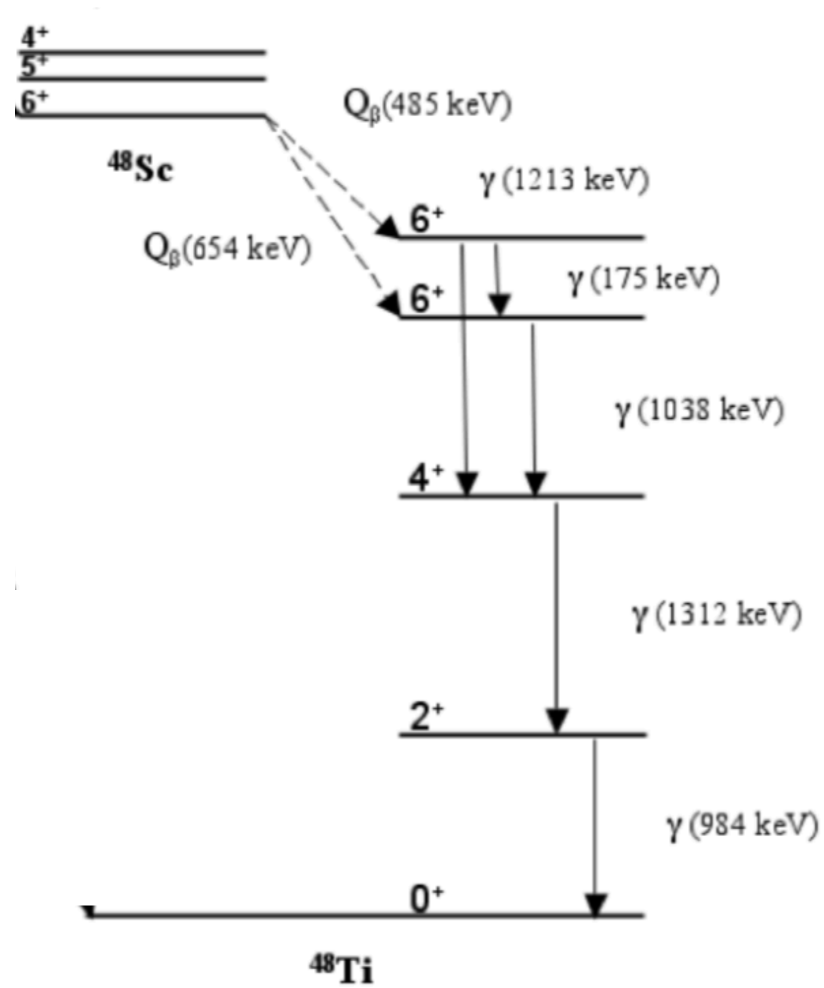
SPIN-DEPENDENT DM

- Direct Detection very hard: velocity suppression
- Indirect limits from mediators:



OTHER ISOTOPE CANDIDATES

^{46}Sc, ^{124}Sb, ^{48}V, ^{154}Eu, ^{207}Bi and finally ^{48}Sc



CONCLUSIONS

- Difficulty with NA64/LDMX type searches for nuclear forces
- Can be looked for in high statistics gamma decay
- Could constrain light dark matter direct detection parameter space without ambiguities of local DM densities and velocities.