PROBING NEW LIGHT FORCE-MEDIATORS BY ISOTOPE SHIFT

Yotam Soreq

ASPEN Winter 2017

J.C. Berengut, D. Budker, C. Delaunay, V.V. Flambaum, C. Frugiuele, E. Fuchs,
C. Grojean, R. Harnik, R. Ozeri, G. Perez, YS - work in progress

C. Delaunay, R. Ozeri, G. Perez, YS 1601.05087

the Standard Model (SM) works great but it is **not** a complete picture

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New Physics (NP) is required but its scale is unknown

THE QUEST FOR NEW PHYSICS

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(TeV scale)

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Roee Ozeri's lab, physics, Weizmann.

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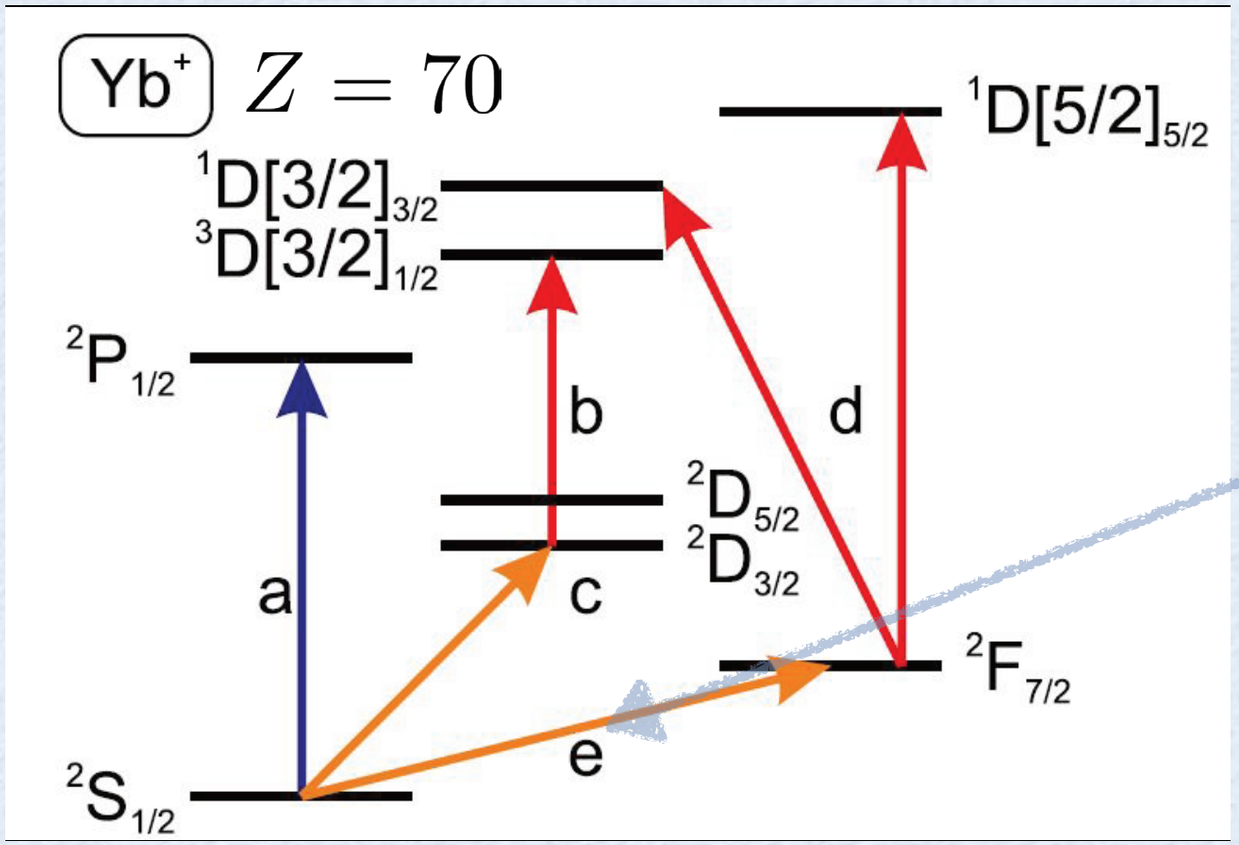
PRECISION SPECTROSCOPY

Ytterbium (Yb^+)



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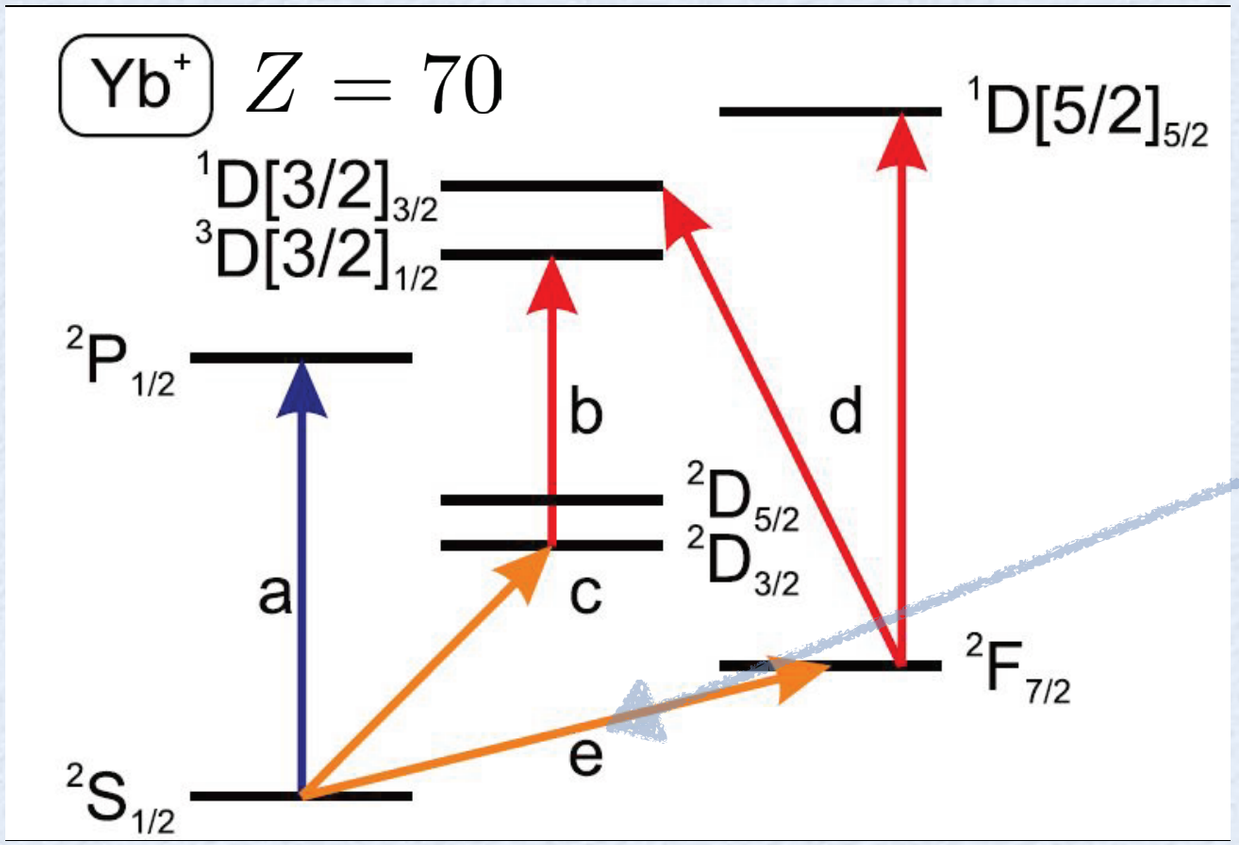

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in principle: $y_e y_n \left(\frac{125\,\mathrm{GeV}}{m_\phi}\right)^2 < 4\times10^{-6}$

stronger than LHC current bounds

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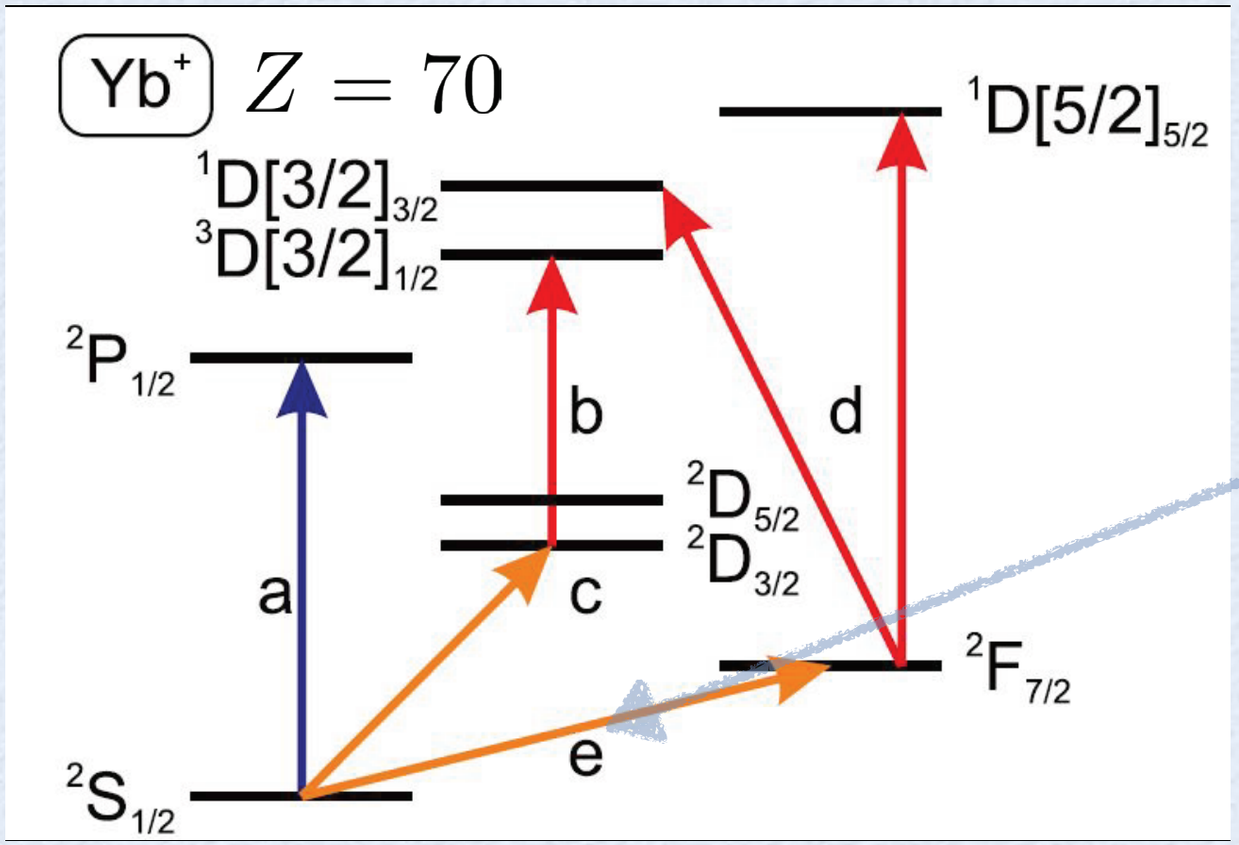

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theory is not good enough

Isotope Shift

ISOTOPE SHIFT - KING PLOT

the **same** electronic transition, *i*, in **two** isotopes, *A* and *A'*

$$\nu_i^{AA'} \equiv \nu_i^A - \nu_i^{A'}$$

King 63

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Mass Shift — Field Shift (short distance)

$$\nu_i^{AA'} \equiv \nu_i^A - \nu_i^{A'} = K_i \mu_{AA'} + F_i \delta\langle r^2 \rangle_{AA'} + \dots$$

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electronic parameters — **nucleus** parameters

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$$\mu_{AA'} \equiv \frac{1}{m_A} - \frac{1}{m_{A'}}$$

$$m\nu_i^{AA'} \equiv \nu_i^{AA'}/\mu_{AA'}$$

$$F_{21} \equiv F_2/F_1$$

$$K_{21} \equiv K_2 - F_{21}K_1$$

i=1,2

$$m\nu_2^{AA'} = K_{21} + F_{21} m\nu_1^{AA'}$$

factorization → linear relation between two transitions

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$$\overrightarrow{m\nu}_i \equiv \left(m\nu_i^{AA'_1}, m\nu_i^{AA'_2}, m\nu_i^{AA'_3}\right)$$

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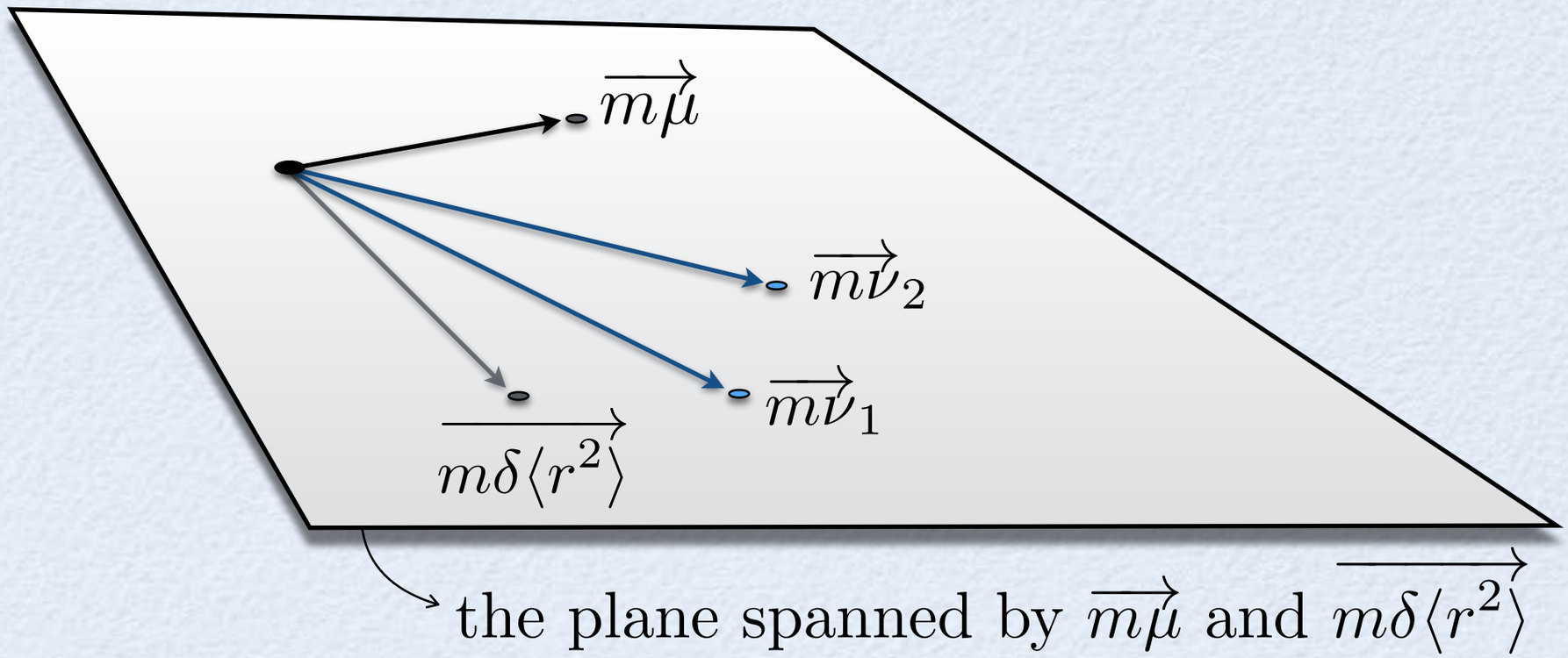
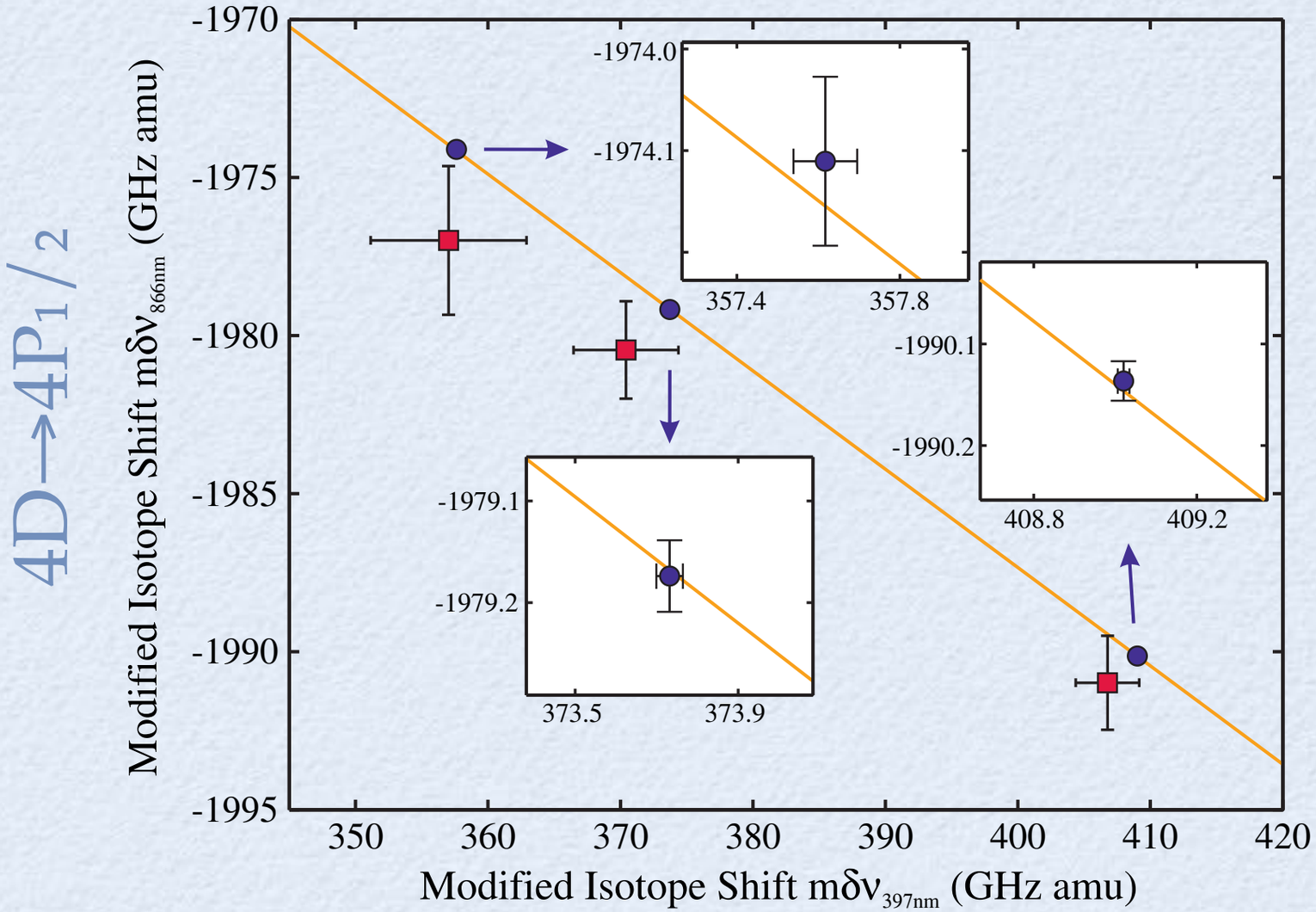


testing factorization only by data

ISOTOPE SHIFT - KING PLOT

existing isotope shift measurement of Ca^+



4D→4P1/2

4S→4P1/2

100kHz error

Gebert et al. 2015

the

for new physics

ISOTOPE SHIFT AND NEW PHYSICS

$$\nu_i^{AA'} = K_i\,\mu_{AA'} + F_i\,\delta\langle r^2\rangle_{AA'} + \alpha_{\rm NP} X_i\,\gamma_{AA'}$$

new physics

ISOTOPE SHIFT AND NEW PHYSICS

$$\overrightarrow{m\nu}_2 = K_{21}\overrightarrow{m\mu} + F_{21}\overrightarrow{m\nu}_1 + \alpha_{\rm NP}\vec{h}\,(X_2 - X_1 F_{21})$$

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$F_{21} \equiv F_2/F_1$

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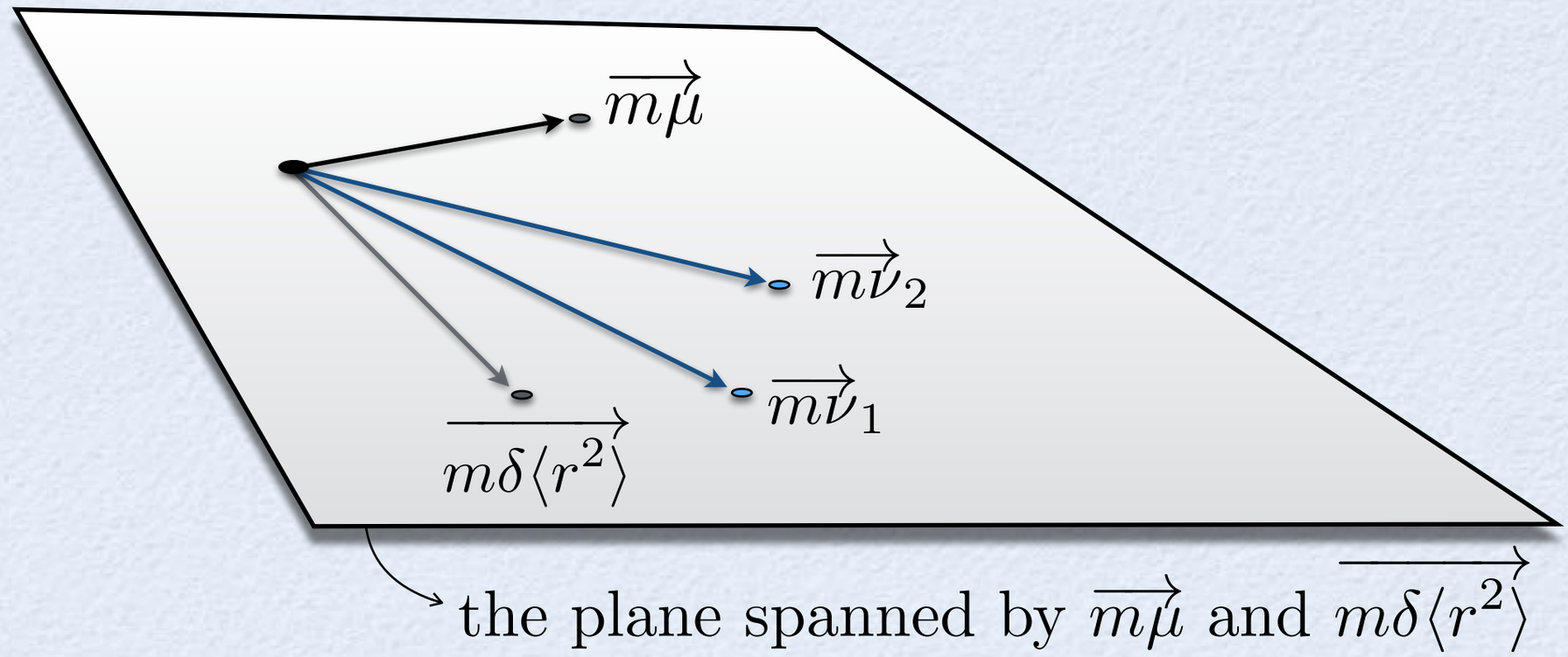

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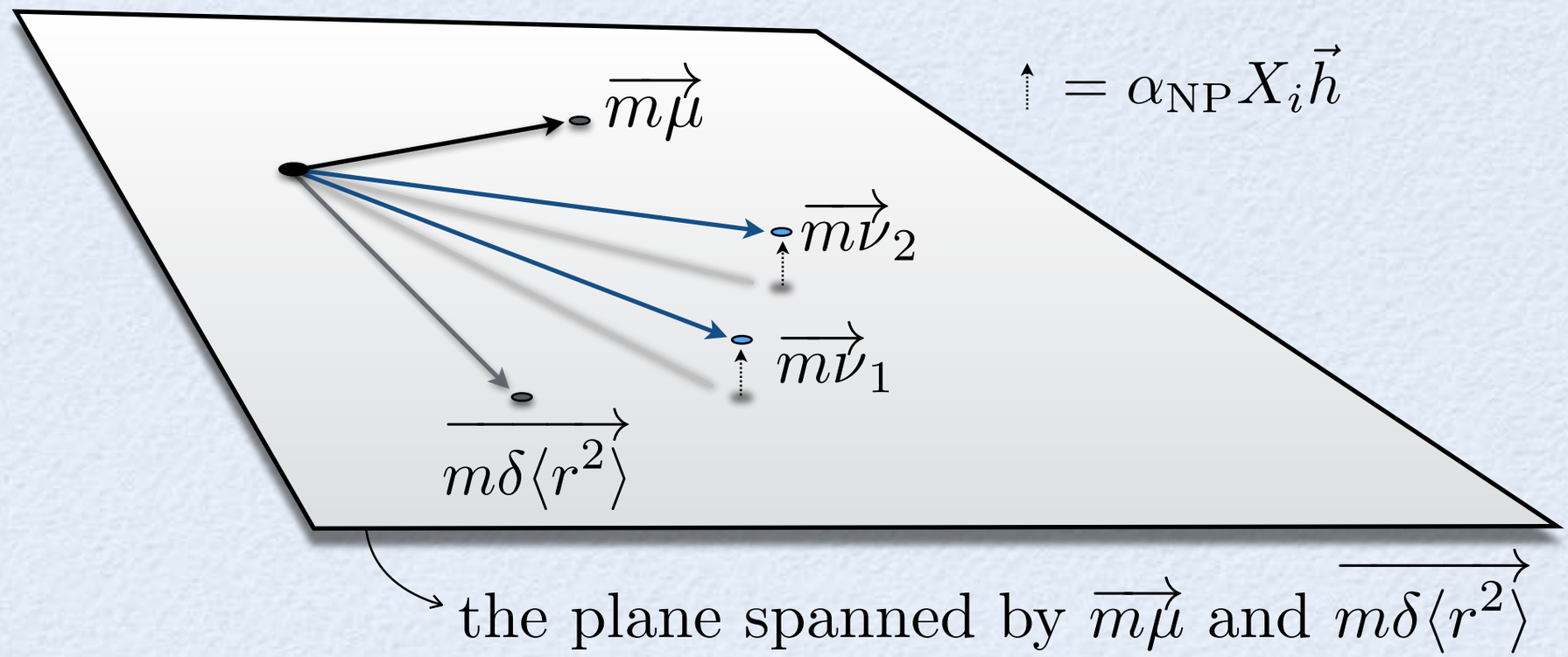

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- h - is not aligned with $m\nu_1$, $m\nu_2$, $m\mu$

nonlinear King plot from NP

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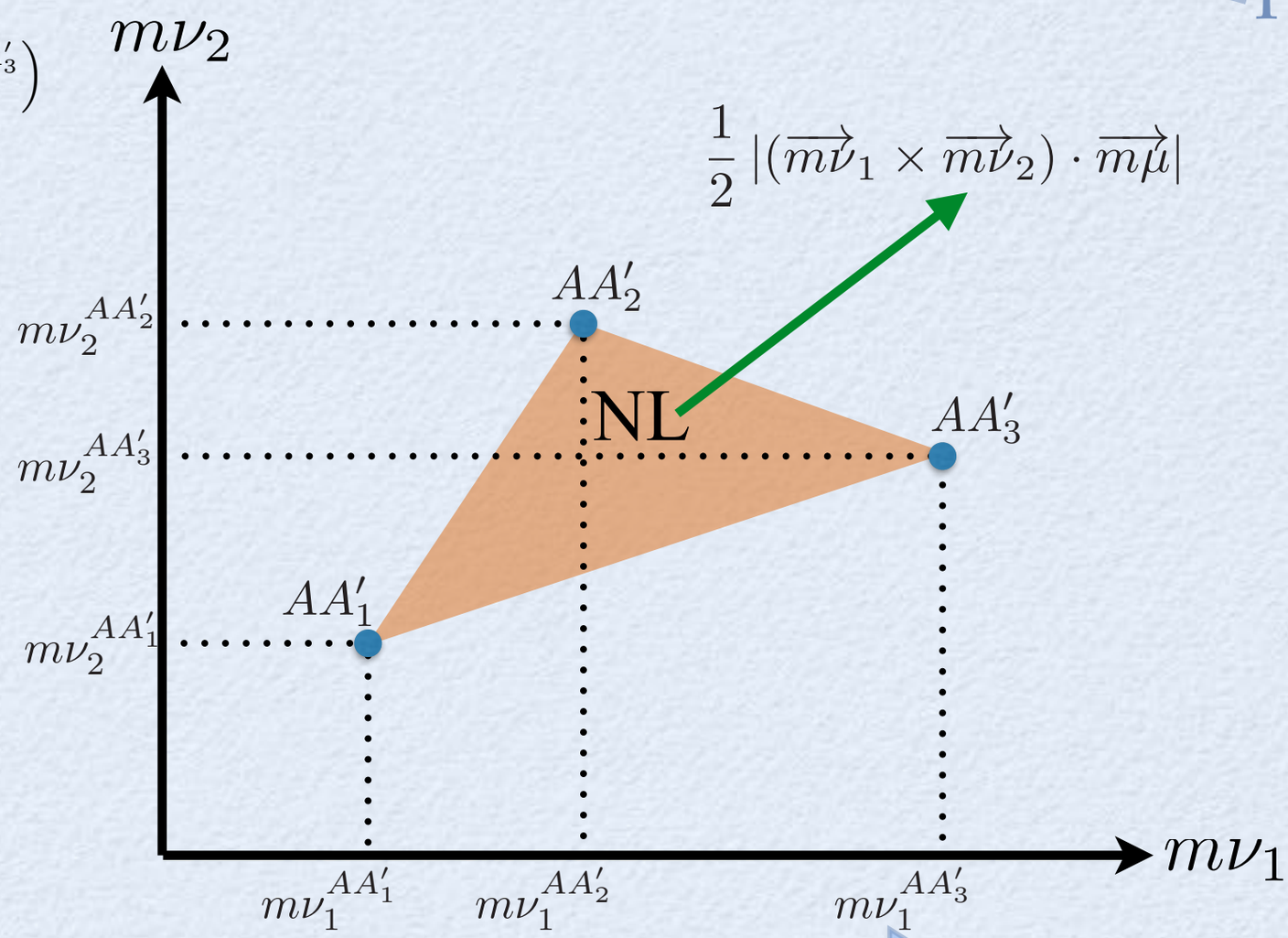

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the *only* theory inputs

similar to data driven background estimation at the LHC

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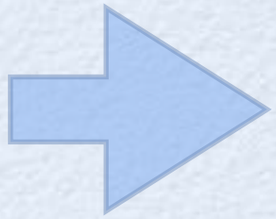

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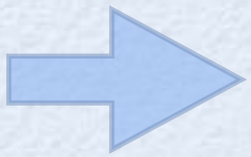

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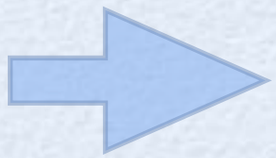
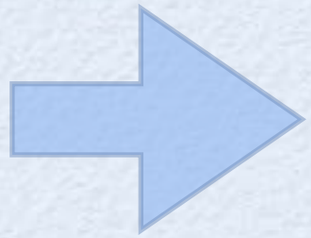
data consistent with linearity



constrain NP

CONSTRAINING LIGHT NEW BOSONS

new bosons with couplings to *e* and *n*
(spin independent)



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1st order perturbation theory and multi-body perturbation theory

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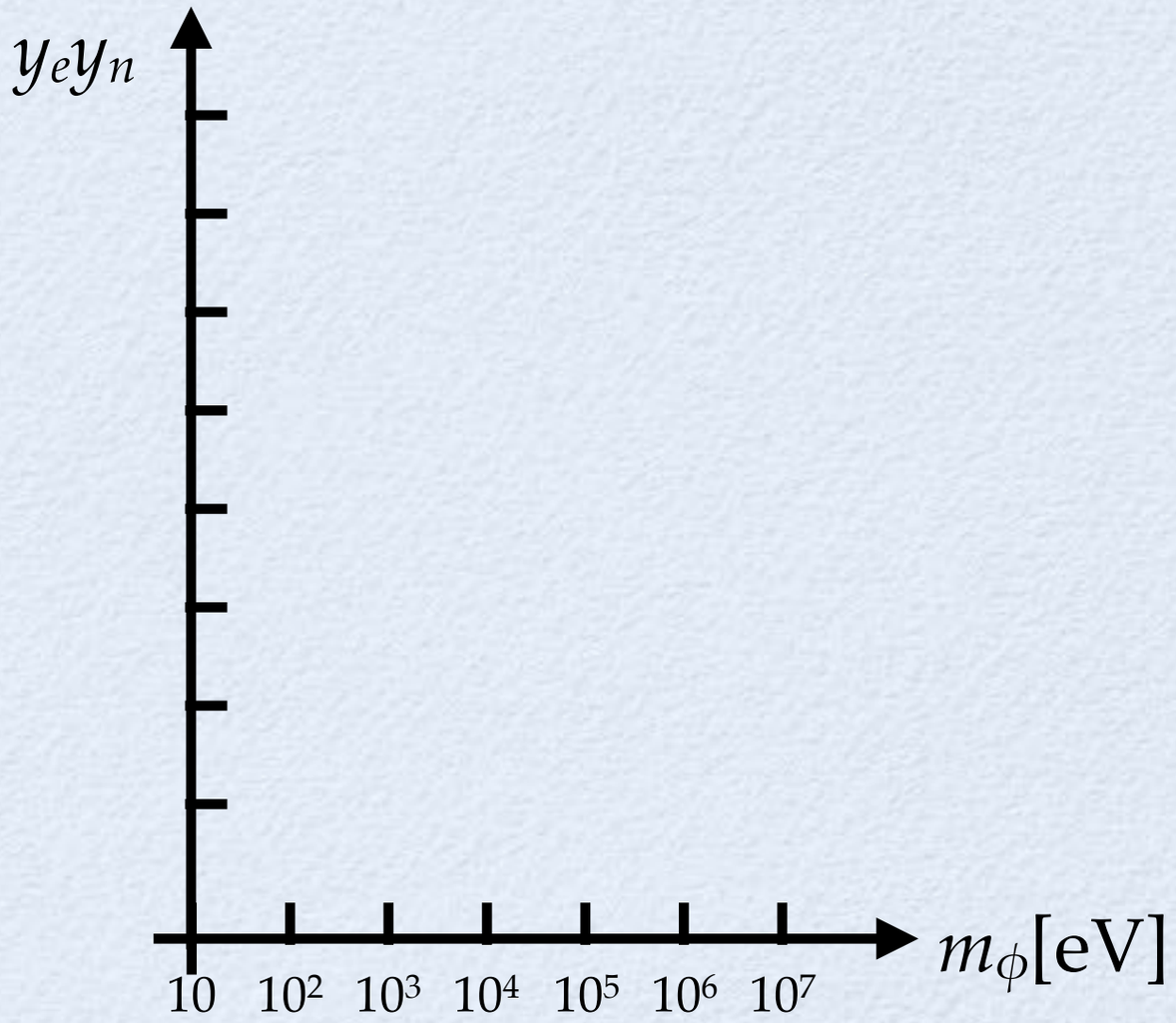
1st order perturbation theory and multi-body perturbation theory

	$m_\phi < 4$keV	4keV $< m_\phi <$ 50MeV	50MeV $< m_\phi$
$V_\phi(r)\sim$	$1/r$	$\exp(-m_\phi r)/r$	$\delta(r)/(m_\phi r)^2$
X_i	constant	m_ϕ dependent	X_2-$X_1F_{21}\rightarrow 0$

CONSTRAINING LIGHT NEW BOSONS

$$y_e y_n < \sigma_i \frac{\sqrt{1+F_{21}^2}}{X_2 - X_1 F_{21}} \frac{4\pi\, A}{(A-A')^2}$$

experimental error



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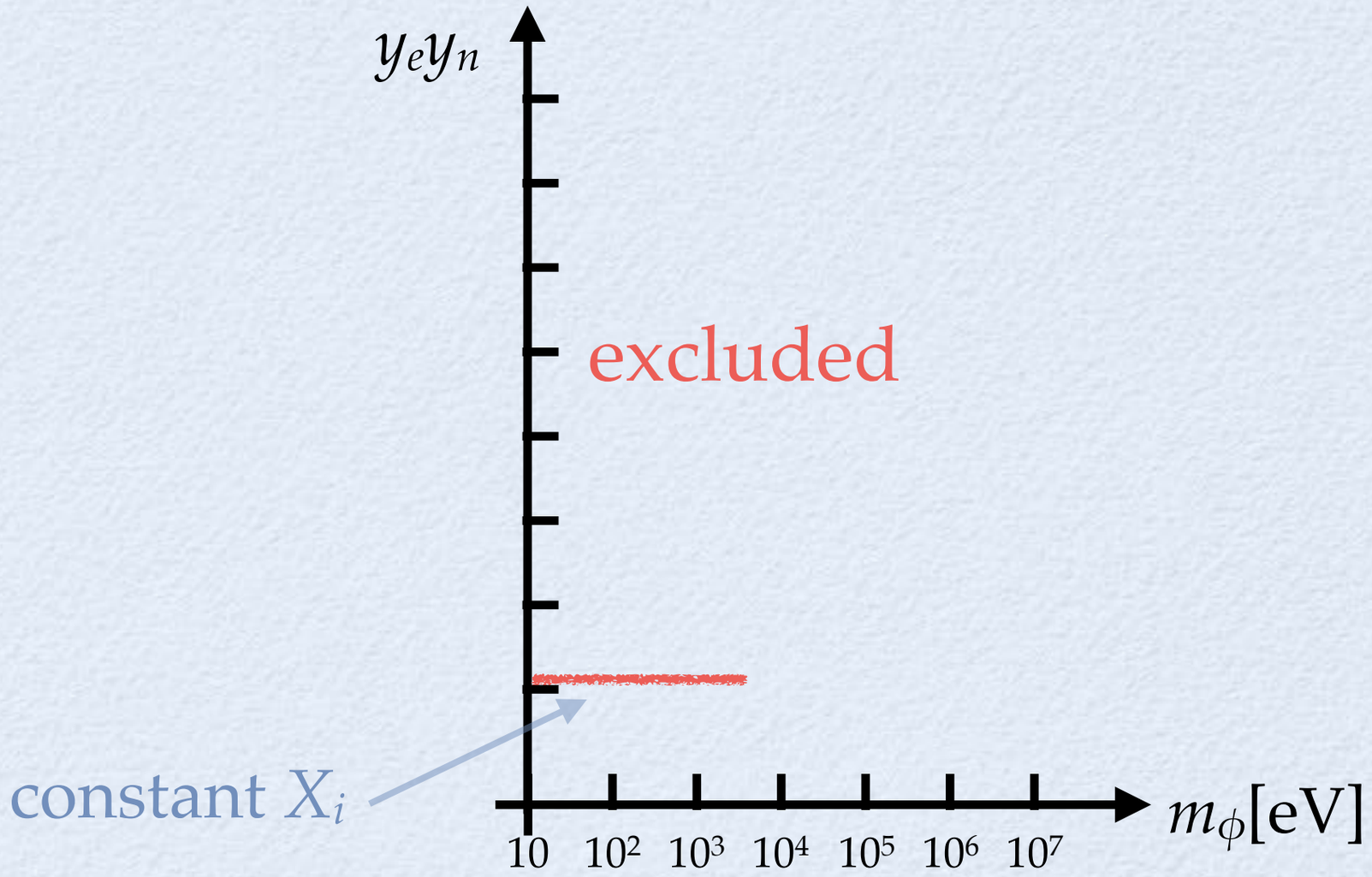

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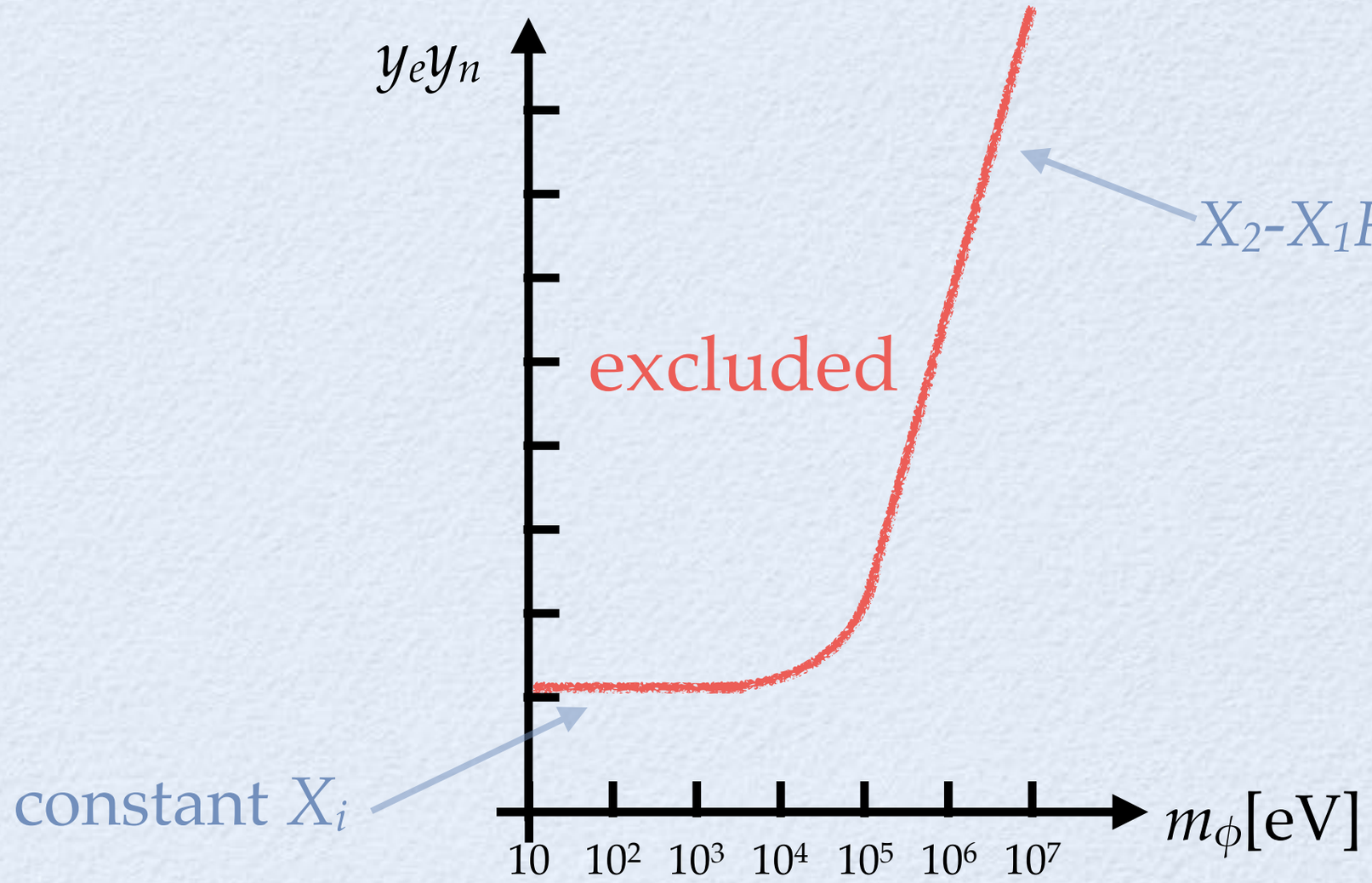

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- current data:
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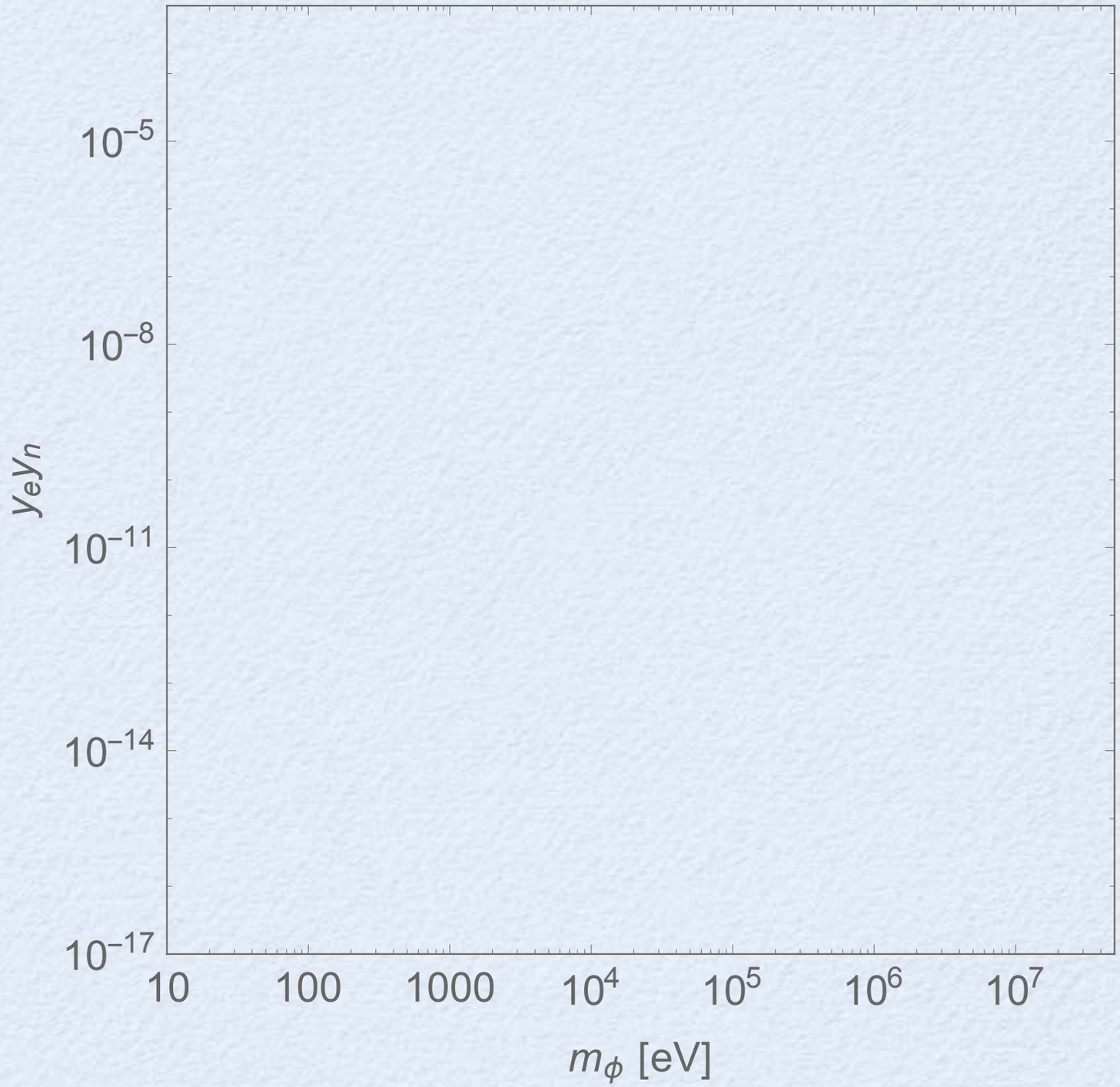
- candidates for future measurements:
  - **Ca^+**: $S \rightarrow D_{5/2}$ / $S \rightarrow D_{3/2}$
  - **Sr^+**: $S \rightarrow D_{5/2}$ / $S \rightarrow D_{3/2}$
  - **Sr^+/Sr**: $S \rightarrow P$ / $S \rightarrow D_{5/2}$
  - **Yb^+**: $S \rightarrow D_{3/2}$ / $S \rightarrow F_{7/2}$

BOUNDS

preliminary



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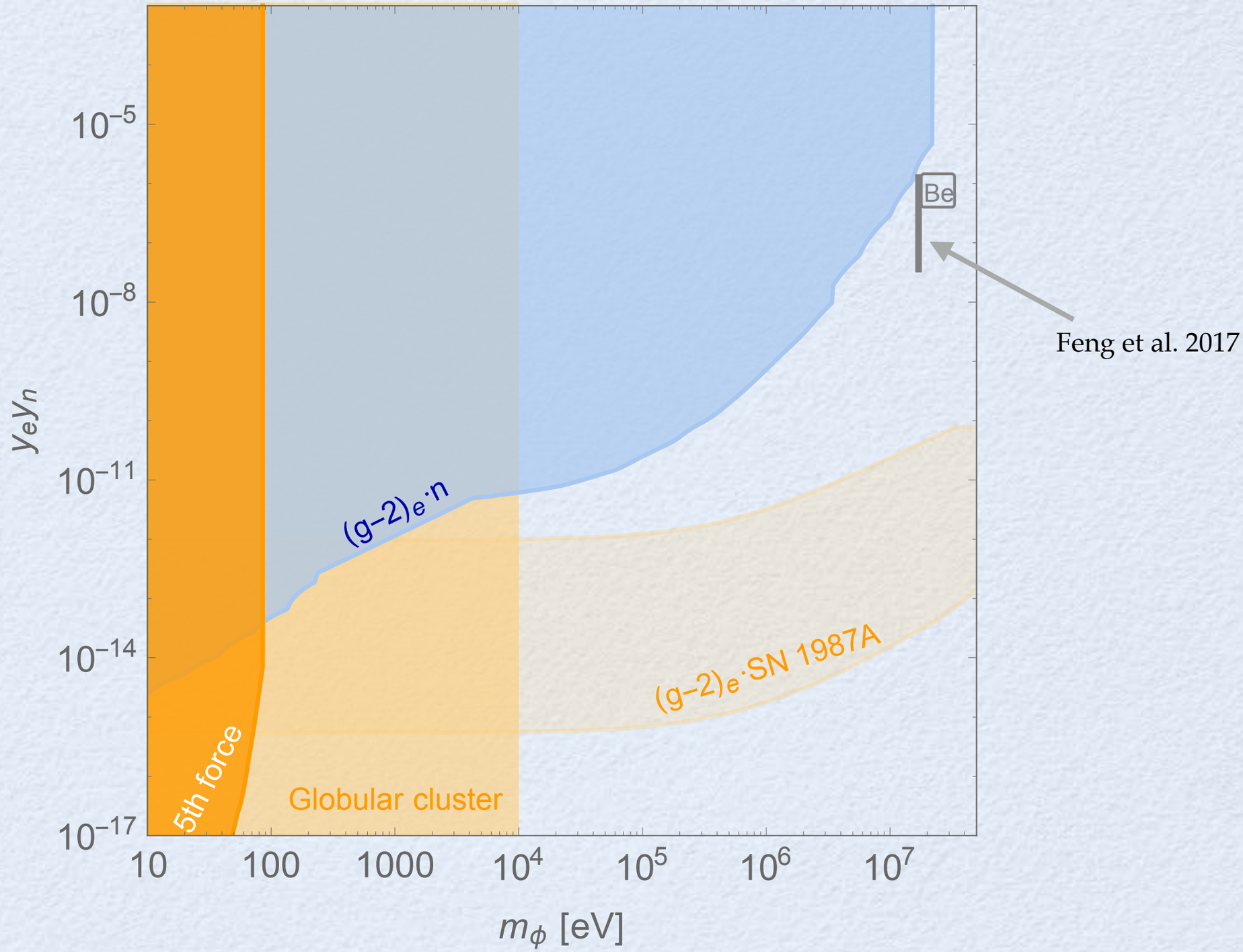

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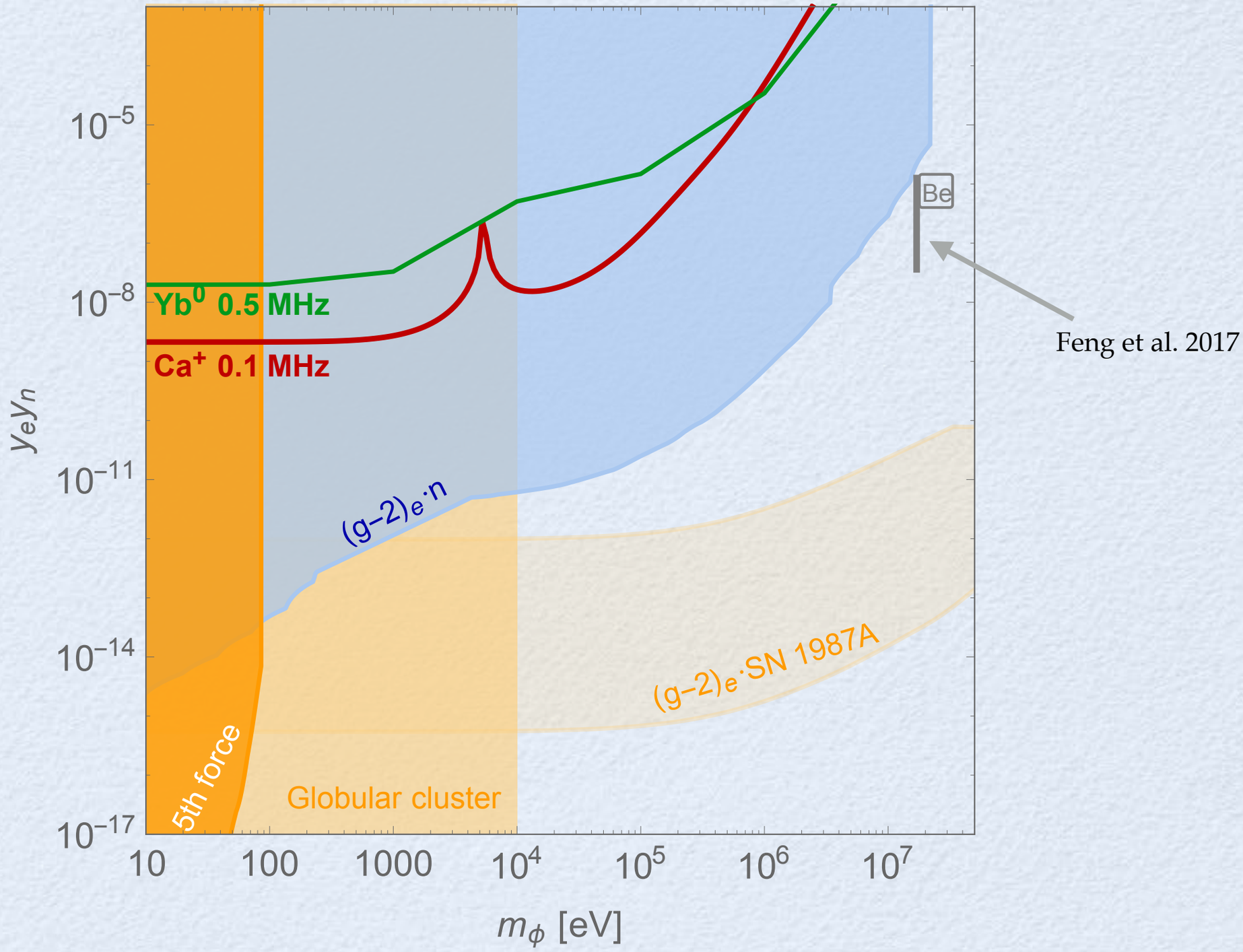

Feng et al. 2017

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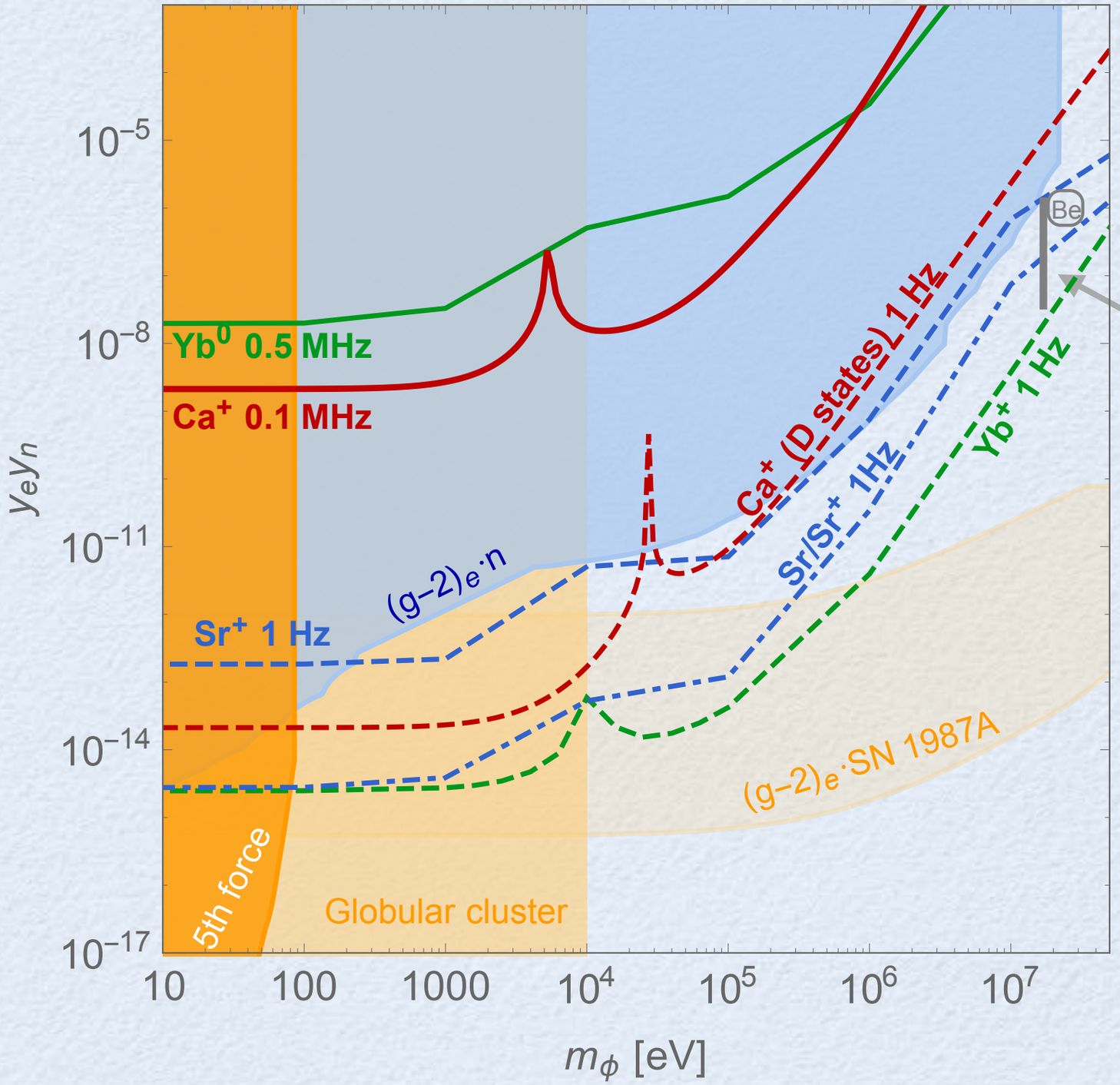

Feng et al. 2017

SUMMARY

- precision isotope spectroscopy can probe new light force-carriers with spin independent couplings to the electron and neutron
- the bounds has minimal theory inputs - only the new physics has to be derived from theory ("data-driven background")
- current constraints are weak - but future measurements may improve the state-of-the-art bounds

BACKUP SLIDES

SM NONLINEARITIES

- in principle - if nonlinearities are measured - correlation between different systems may help to distinguish between SM or NP
- from higher-order SM effects
- dominant effect from corrections to field shift (2nd order perturbation theory)

$$m\nu_i^{\mathrm{II}} = \sum_k |\langle k|\hat{O}_{\mathrm{FS}}|i\rangle|^2/\Delta E_k \sim (m\nu_i^{\mathrm{I}})^2/\Delta E$$