Probing New Physics at Underground Accelerators and Radioactive Sources

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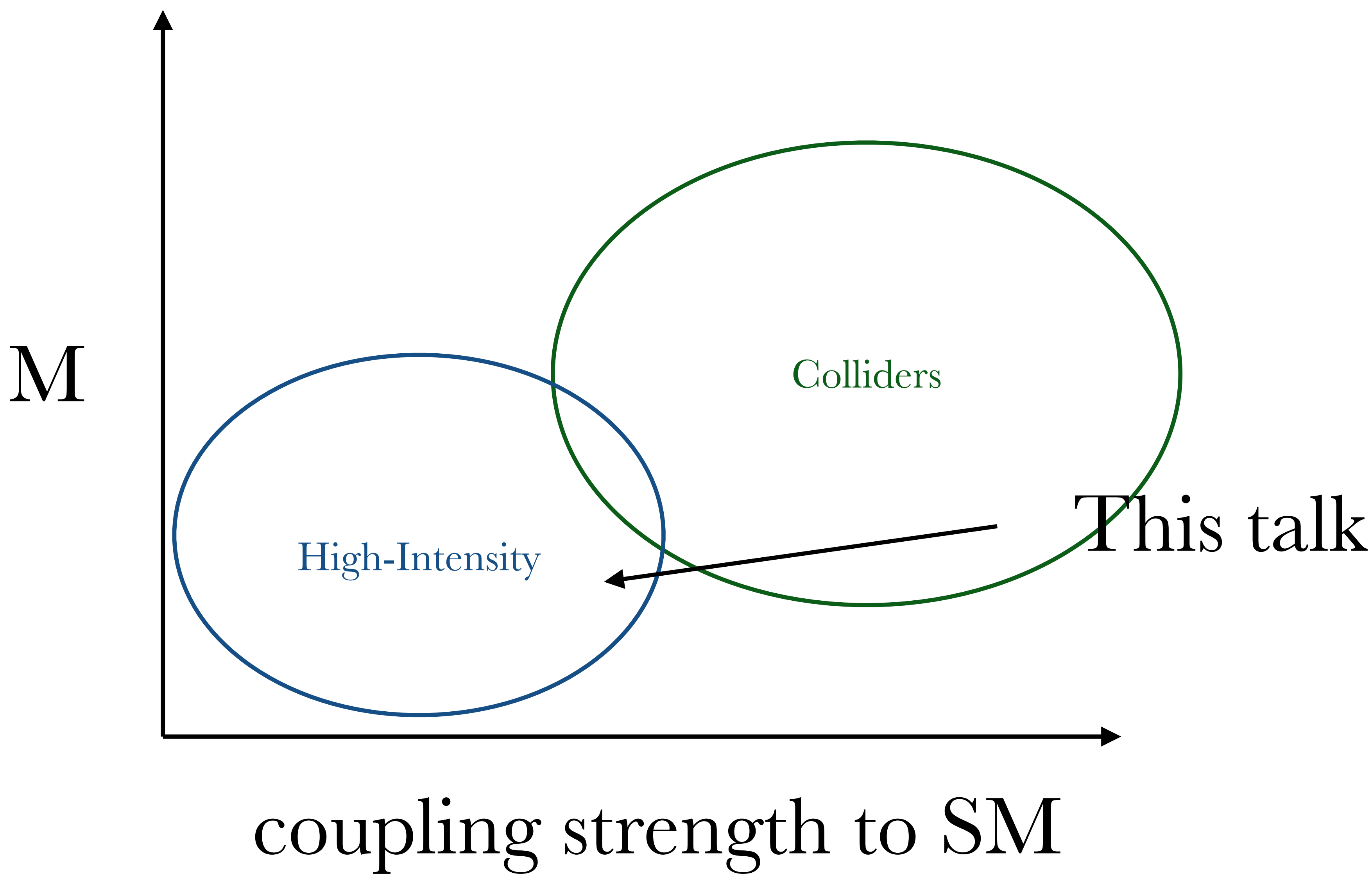
Outline

Experimental Opportunities ★

The Proton Charge Radius

(Directly) Looking for New Physics



High Intensity Experiments

A lot of effort in the community
Probing interesting models with **existing** experiments

e.g. neutrino experiments
can accommodate (parasitic or near-parasitic or recast)
probes of new physics

Other targets of opportunity we can exploit?

Low Energy Experiments Land

Within high-intensity experiments
$E \sim$ 1-10 GeV considered the "energy frontier"

How about on the other end of the energy spectrum?

e.g. facilities with $E \sim$ MeV or less

What possibilities could they offer
in probing new physics scenarios?

Underground Accelerators

The testing ground of nuclear astrophysics

Intended to measure the (tiny) rates
of nuclear reactions inside stars

These reactions take place at small energies
E ~ 100 KeV - MeV

High enough to overcome the Coulomb repulsion
Small enough to have enough thermal population

Typically feature proton/ion beams with 1-100 mA currents

Underground Accelerators Setup

A few facilities in the world
e.g. LUNA at Gran Sasso
DIANA at Sanford

LUNA capable of accelerating proton or He ions

Currently has two accelerators:
a 50 KeV home-made version
and a 400 KeV commercial accelerator

The “energy-frontier” expected to feature 3 MeV proton beams at LUNA-MV and DIANA

The Neighbours of Underground Accelerators

Some of these accelerators are in the same facility where large neutrino or DM detectors reside

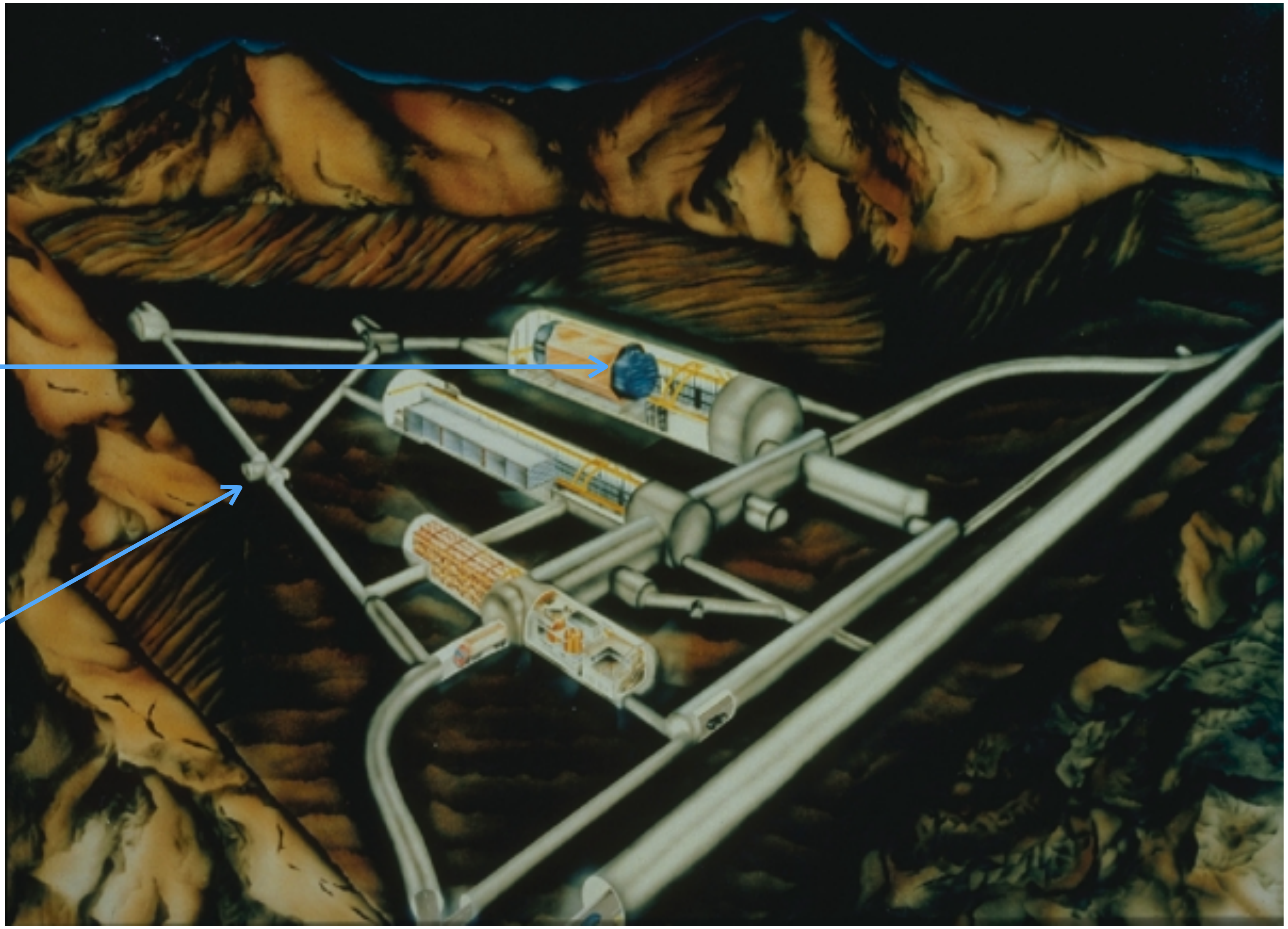
LUNA is within ~ 100 meters of Borexino

LUNA-MV expected to be ~ 15 m from Borexino

DIANA's neighbour: LUX

Gran Sasso Layout

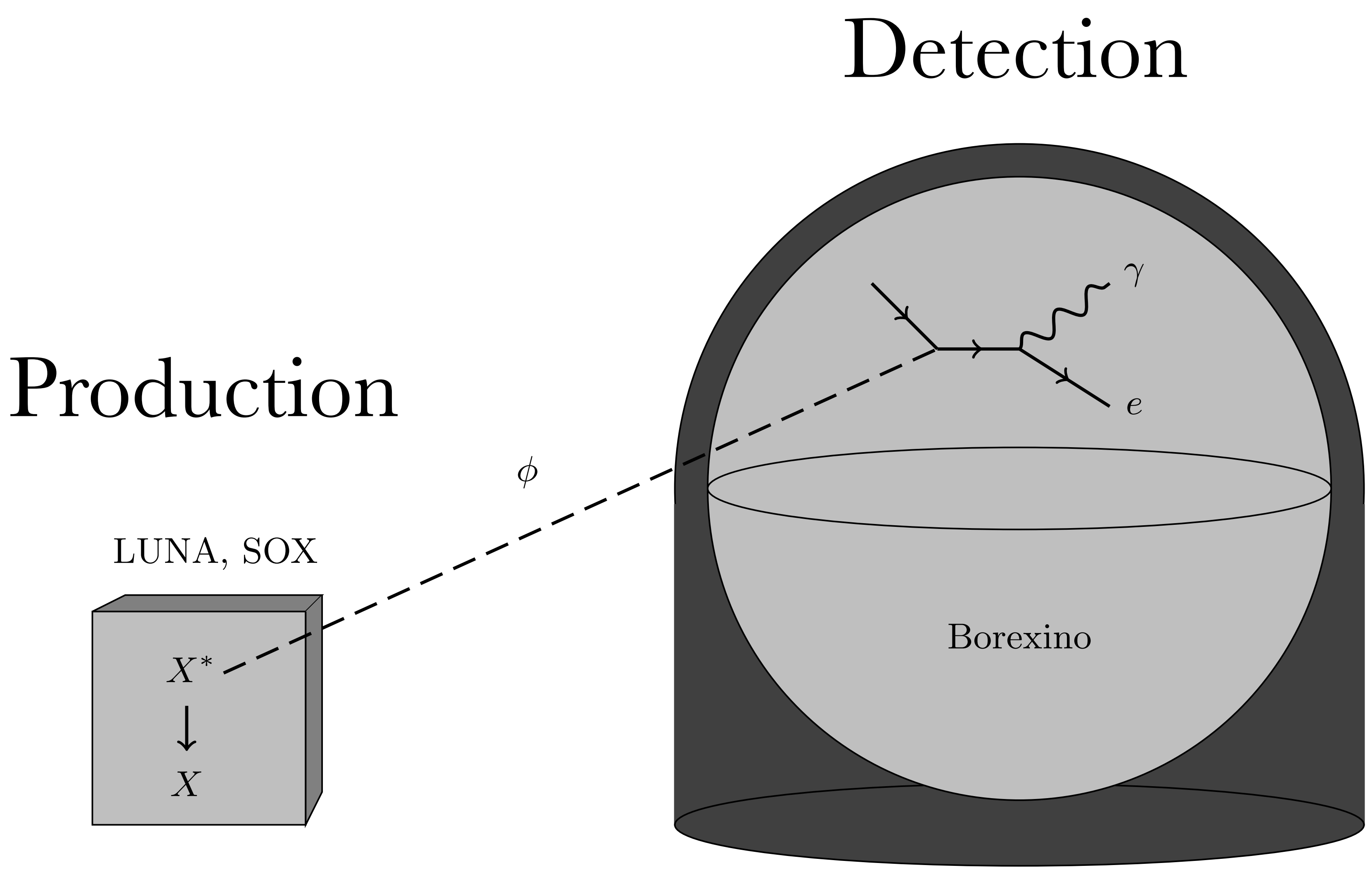
Borexino



LUNA

Set-Up at Underground Accelerators and Radioactive Sources

Set-up



A Neat Reaction at Underground Accelerators

How about looking for a NP signal in a reaction where the SM is suppressed?

$$^{16}O^*(6.05\ \mathrm{MeV}) \to ^{16}O + X$$

0^+ decays to 0^+ → $X = e^+e^-$

SM suppressed

A new light scalar would feature an enhancement in rate!

$$^{16}O^*(6.05\ \mathrm{MeV}) \to ^{16}O + \phi$$

$$\text{Enhancement} \sim \left(\frac{\text{num. factor}}{\alpha_{\mathrm{EM}}}\right)$$

Production

Assume a C_3F_8 Target

Can generate the reaction

$$p^{19} + F \rightarrow \alpha +^{16} O^*$$

This reaction has a cross section ~ 20 mb above 1.5 MeV
Append Coulomb tail for extrapolation to lower energies

Followed by

$$^{16}O^*(6.05\ \mathrm{MeV}) \rightarrow^{16} O + \phi$$

Detection

Mono-energetic scalar produced

Absorbed within Borexino (liquid scintillator) or equivalent with cross section

$$\sigma_{\phi e} \approx 10 \text{ mb } (g_e/e)^2$$

At 6 MeV, Borexino offers an extremely clean signal region

Alternative: Radioactive Sources

Existing proposals to place an intense radioactive source near a large detector (Source from spent chemical fuel)

Example: SOX proposal near Borexino
Designed to study short-baseline neutrino oscillations

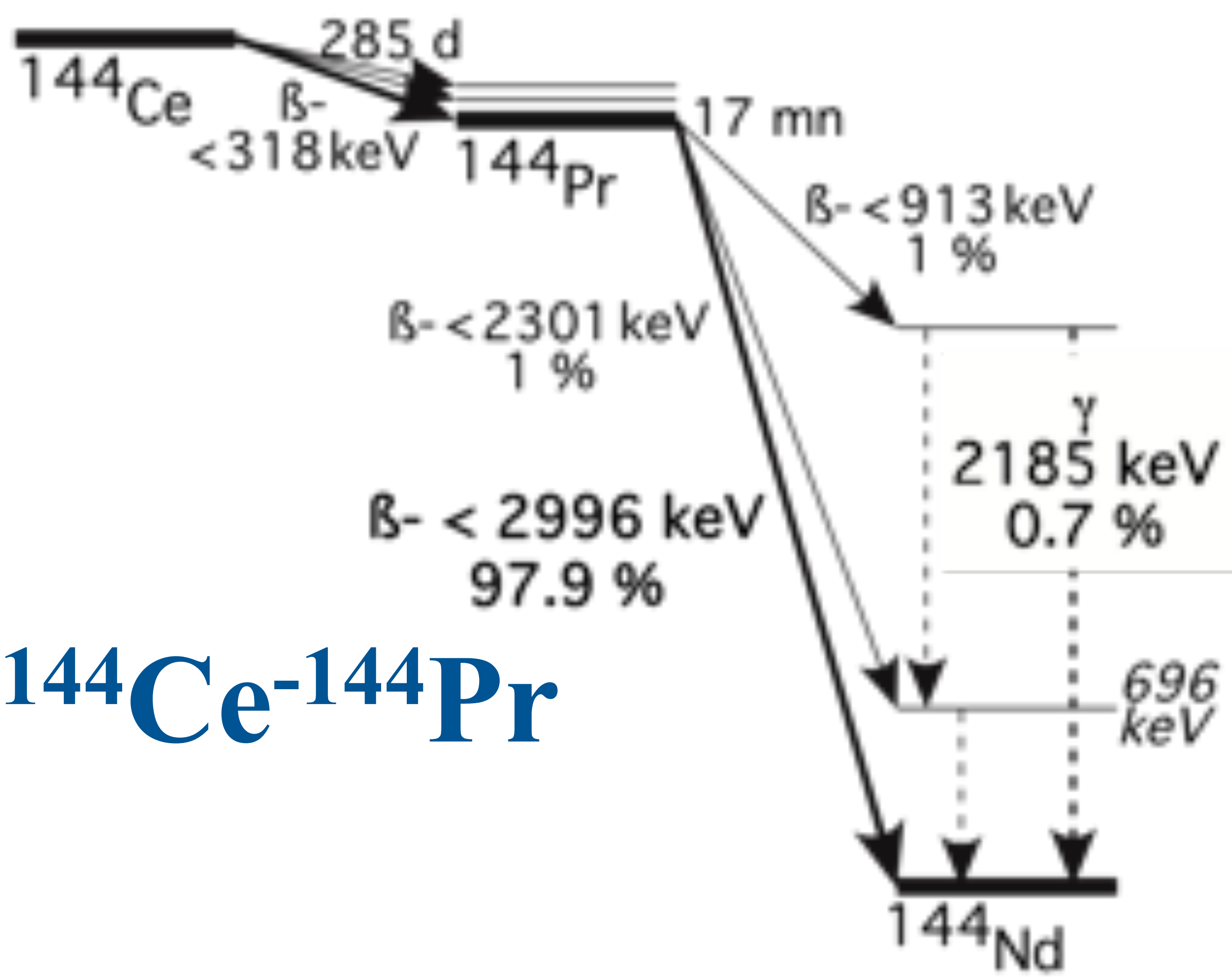
Phase A: Intense ^{51}Cr source ~ 8 m from Borexino

Phase B: $^{144}Ce -^{144}Pr$ source ~ 7 m from Borexino

Phase C: $^{144}Ce -^{144}Pr$ source inside Borexino

Radioactive Sources

Phase B: 2 PBeq source



^{144}Ce-^{144}Pr

Two gammas at 2.2 MeV and 1.5 MeV

Production and Detection at Radioactive Source

Production can either be 2.2 MeV or 1.5 MeV scalar

Absorbed at Borexino with
cross section

$$\sigma_{\phi e} \approx 10 \text{ mb } (g_e/e)^2$$

Lower energy, but still a very clean signature
at Borexino

Outline

Experimental Opportunities

The Proton Charge Radius

The Successful SM

Some well known puzzles

As well as outstanding anomalies

e.g. muon g-2, proton charge-radius

What if the proton charge-radius is coming from New Physics?

The Proton Charge Radius Anomaly

Different ways to extract R_p

Electron-proton scattering

Spectroscopy

And also from muonic Hydrogen
(extracted from the Lamb Shift)

The Proton Charge Radius Anomaly

Different ways to extract R_p

e-p scattering	$r_p = 0.879(8)$ fm
Spectroscopy	$r_p = 0.8768(69)$ fm
muonic-H	$r_p = 0.84184(67)$ fm

Large discrepancy $(> 5\sigma)$

A New Physics Explanation (Wink Wink)

One possible explanation: A new force between the electron/muon and the proton

Tucker-Smith and Yavin, Barger et. al., Batell, McKeen, Pospelov

Here I consider a scalar-mediated force
Need g ~ 10^{-4} to explain r_p

Light ~ MeV scalars a surprising blind spot

The scalar-mediated force changes the binding energy of regular and muonic hydrogen differently
Assume Yukawa-weighted couplings

$$\mathcal{L}_\phi = \frac{1}{2}(\partial_\mu \phi)^2 - \frac{1}{2} m_\phi^2 \phi^2 + (g_p \bar{p} p + g_e \bar{e} e + g_\mu \bar{\mu} \mu)\phi$$

Constraints on < MeV Scalars

LSND
Production via pion absorption

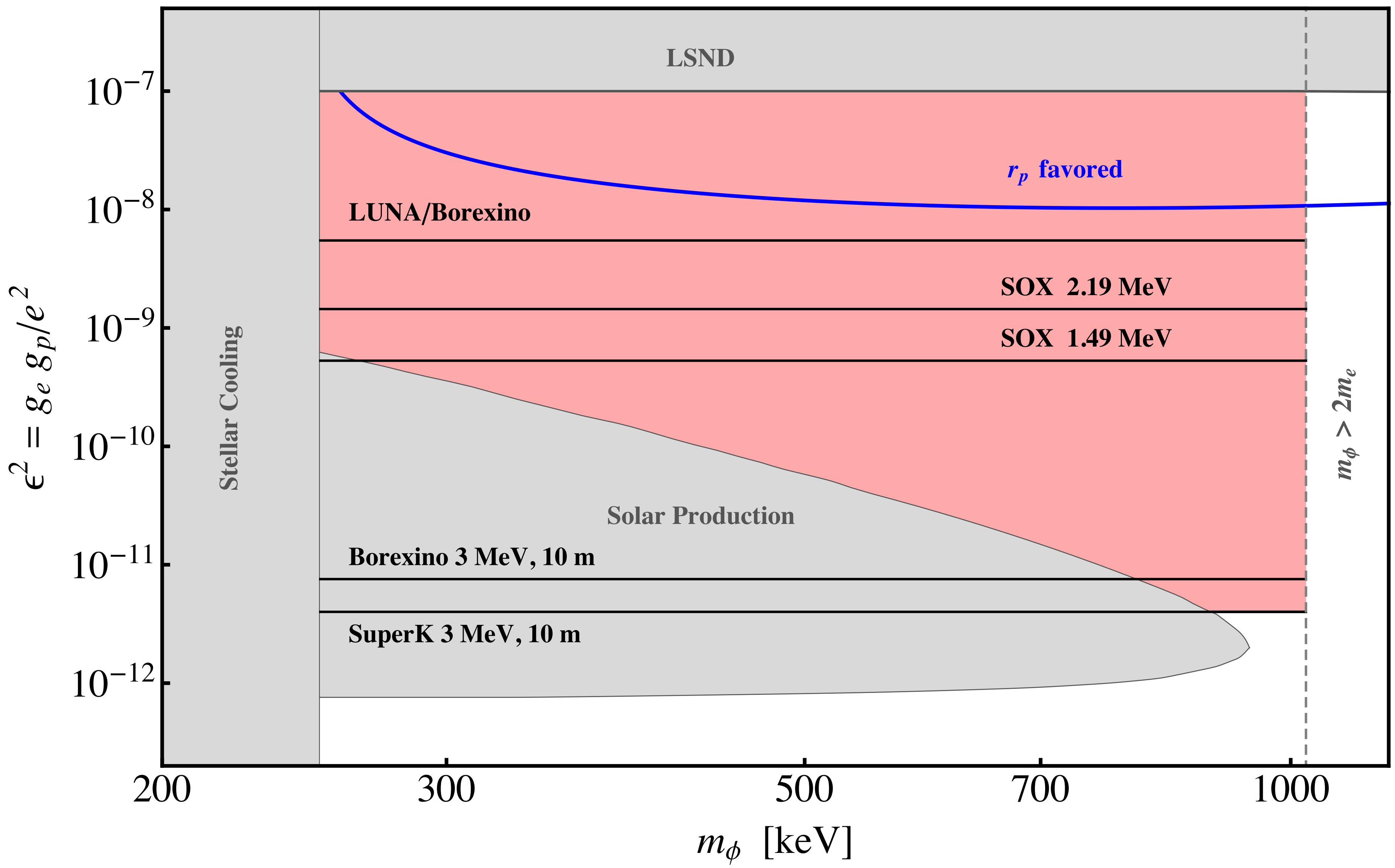
$$\pi^- + p \to n\phi$$

Stellar cooling upper bounds
(Red giants, etc)

Solar axion searches at Borexino
Via the reaction

$$p + d \to He + \phi$$

Potential Sensitivity



Conclusions

Discussed two experimental facilities
Could offer new target of opportunities

Involve emission of a new mediator at nuclear reactions

These facilities conveniently located near large detectors

Application example: The r_p puzzle