TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

New Directions

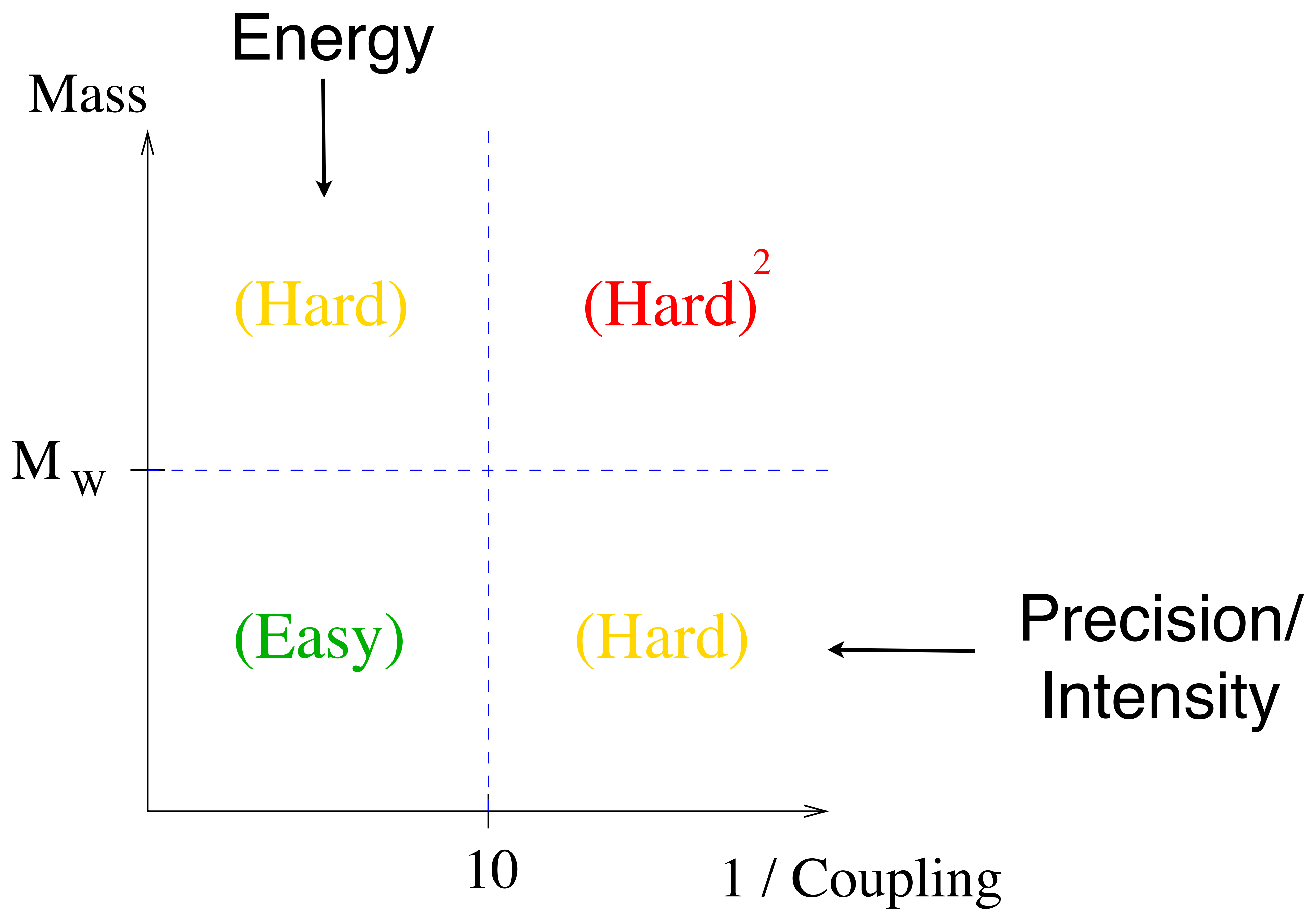
TRIUMF Science Week 2017

[Summary by D.E. Morrissey]

Overview

- Goals:
  - test fundamental physics to greater precision
  - discover new phenomena
- Tools:
  - higher energy
  - higher precision and intensity
- Higher energy usually requires large colliders (LHC, ILC, ...). Increasing precision/intensity may be possible in smaller exps.

- Searching for new phenomena:



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Some Ideas

- Atomic methods for fundamental physics
- Searches for light dark sectors
- Searches for very light dark matter or axions
- Positronium and muonium
- Tests of sterile neutrinos
- Precision Higgs measurements beyond the (HL-)LHC
- Cosmology: CMB, 21cm radiation, ...

Atomic Methods for Fundamental Physics

- Atomic interferometry (AI) is the precision frontier.
- Can be used to probe gravity effects: [Dimopoulos, Graham, Hogan, Kasevich 2008]
  - launch cloud of cold atoms upwards into vaccum
  - split into superposition of momentum states with laser pulse
  - unsplit momentum states with laser pulse
  - recombine (spatially) and measure the phase shift via interference
- Applications include tests of GR and searches for grav. waves.

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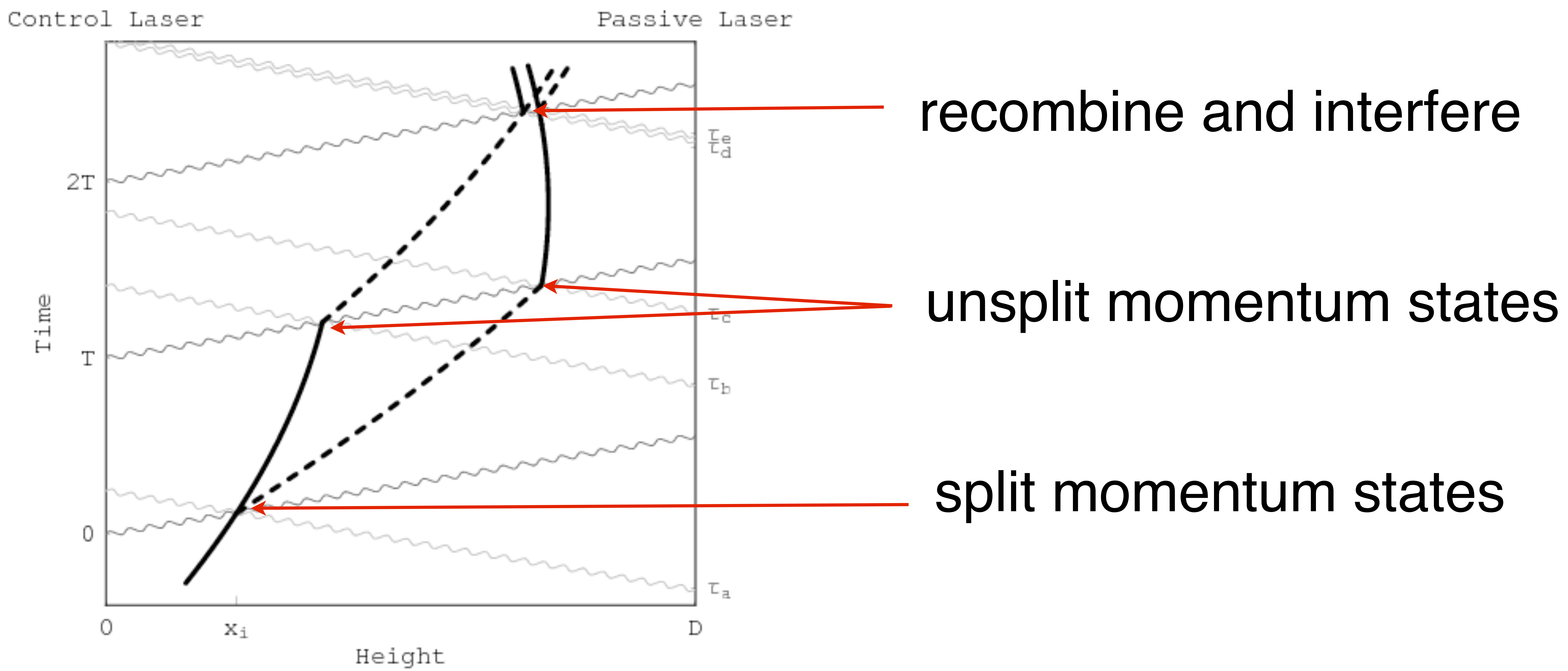
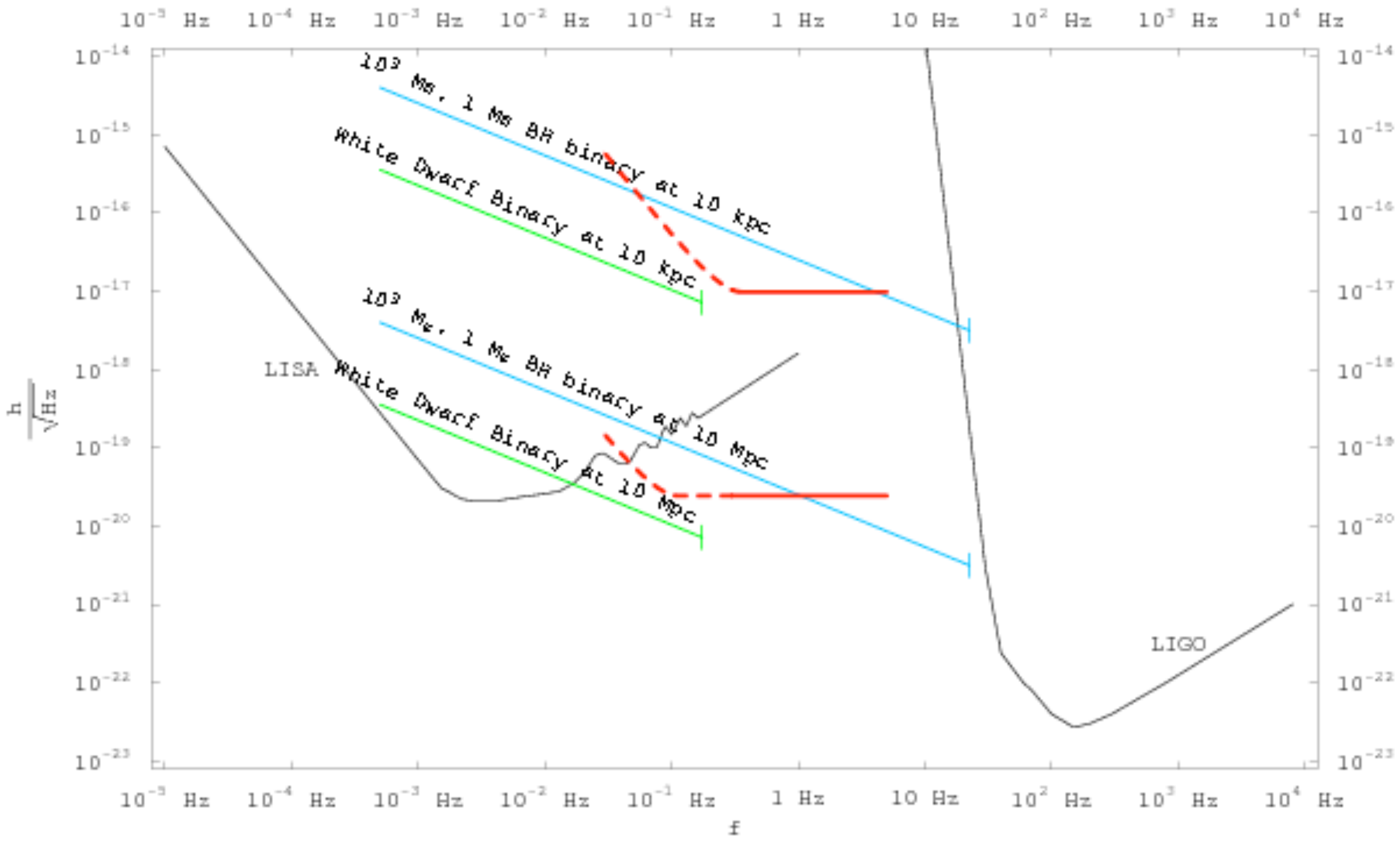


Atomic Methods for Fundamental Physics

- Applications:
  - precision tests of GR (equivalence principle, self-coupling,...)
  - detection of gravity waves (AGIS) or varying constants



[Dimopoulos, Graham, Hogan, Kasevich 2008]

- two 10m tall evacuated apparati
- 1km separation

- Many other methods and possibilities... [*e.g.* Arvanitaki *et al.* 2016]

Light Dark Sectors

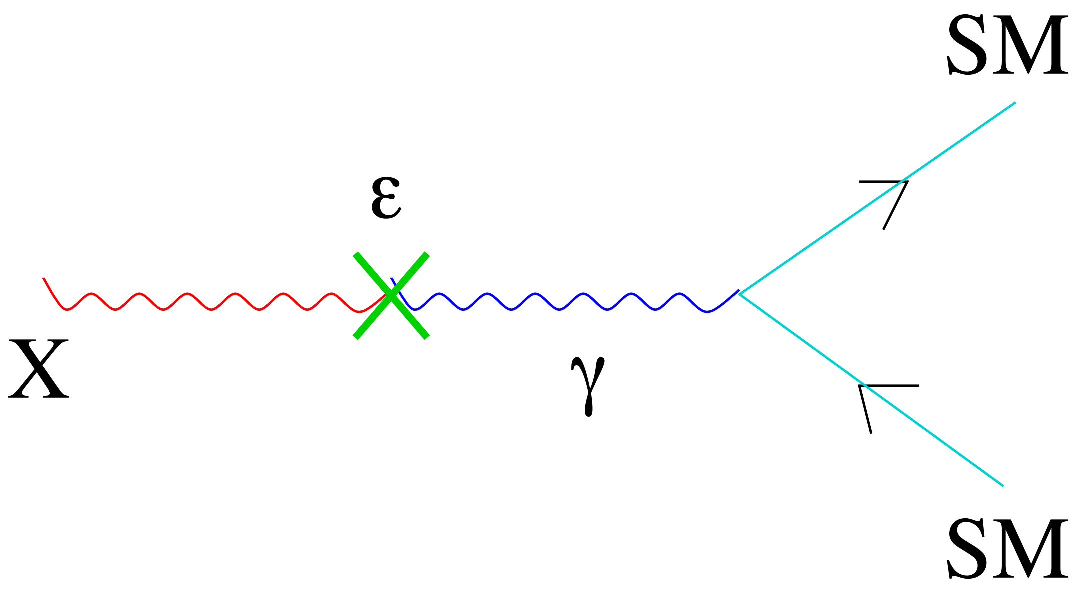
- DM may interact through new forces.

  e.g. new U(1) gauge boson → "dark photon" (usually massive)

- A dark photon might decay to invisible dark particles.

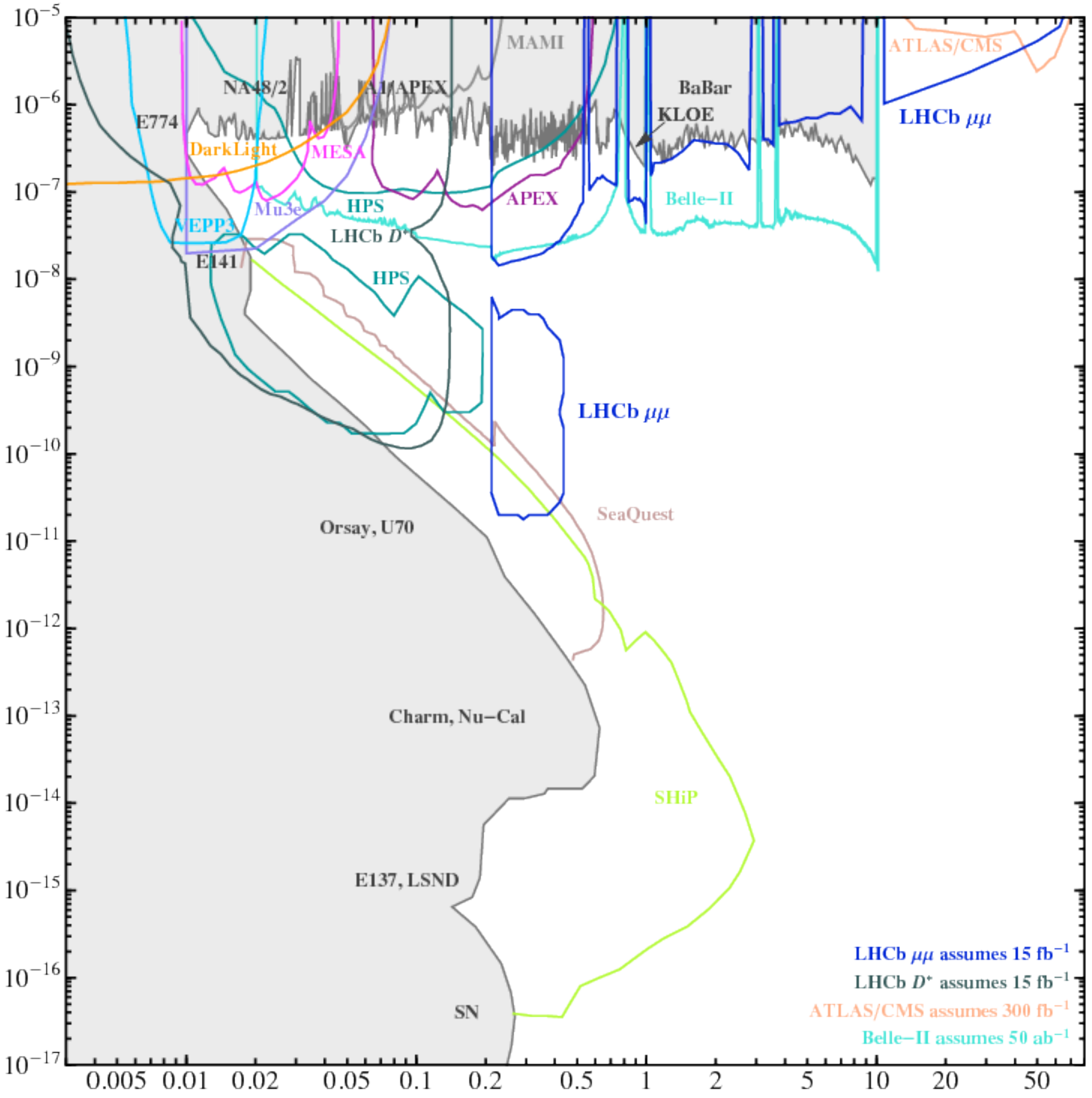
- It could also decay visibly through kinetic mixing:

[Holdom 1986]



- Visible dark photon bounds:

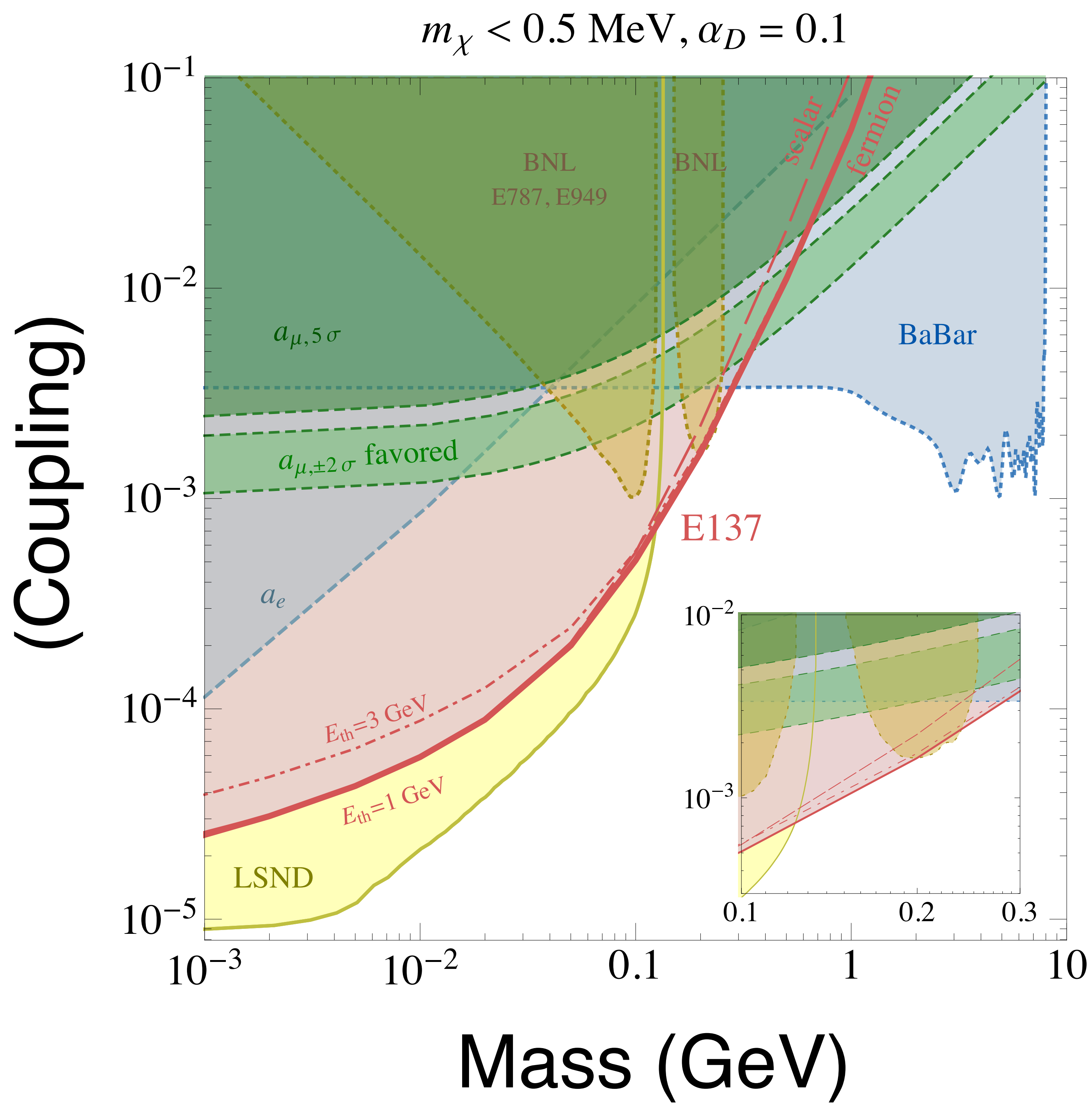
(Coupling)^2



Mass (GeV)

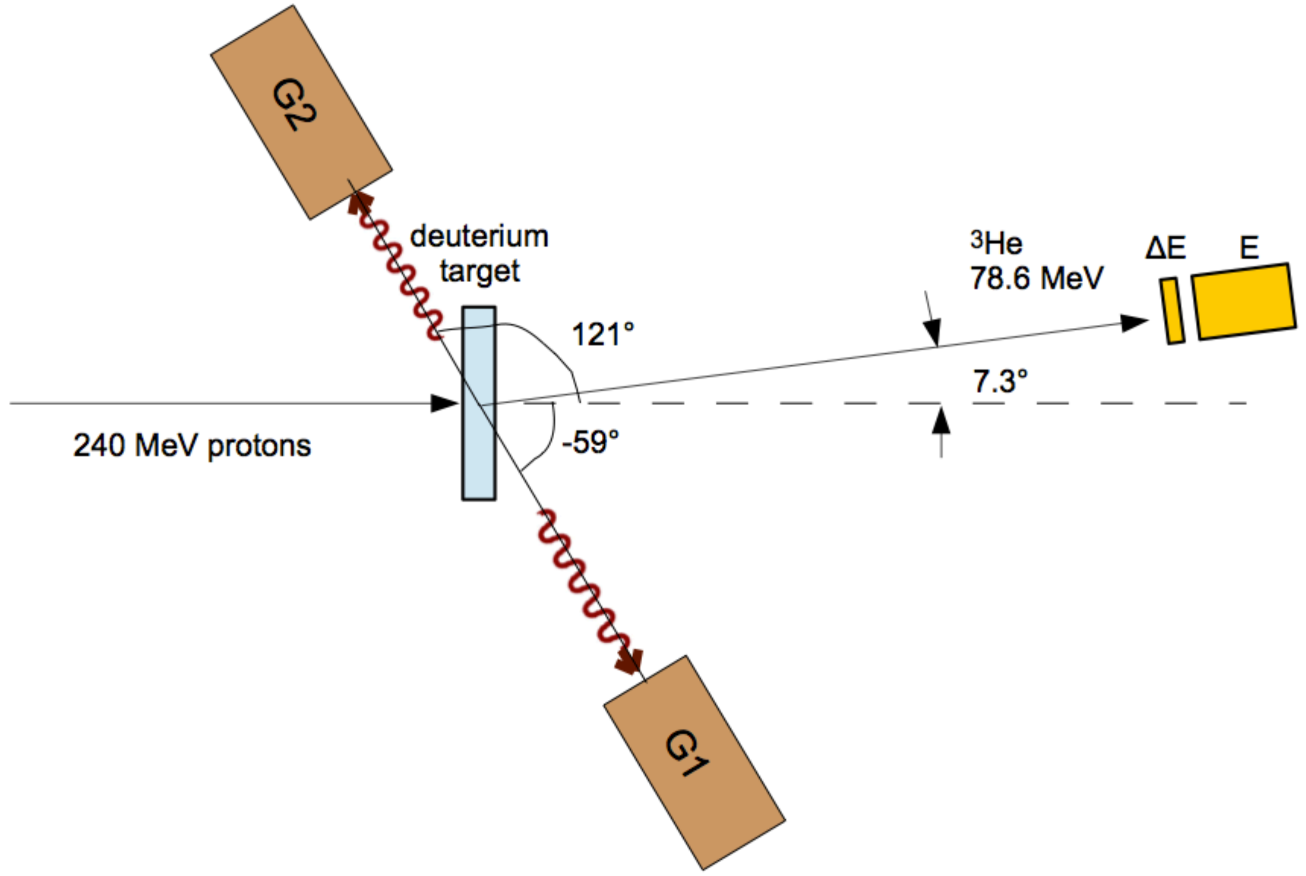
[Ilten, Soreq, Thaler, Williams, Xue 2016]

- Invisible dark photon bounds:



[Batell, Essig, Surujon 2014]

- Detection ideas:
    - dark photon from ARIEL beam dump (Doria)
    - invisible/long-lived dark photon in T2K/HyperK near detector (Ritz)
    - dark photon from neutral pion decay in $p + d \rightarrow ^3\mathrm{He} + \pi^0$



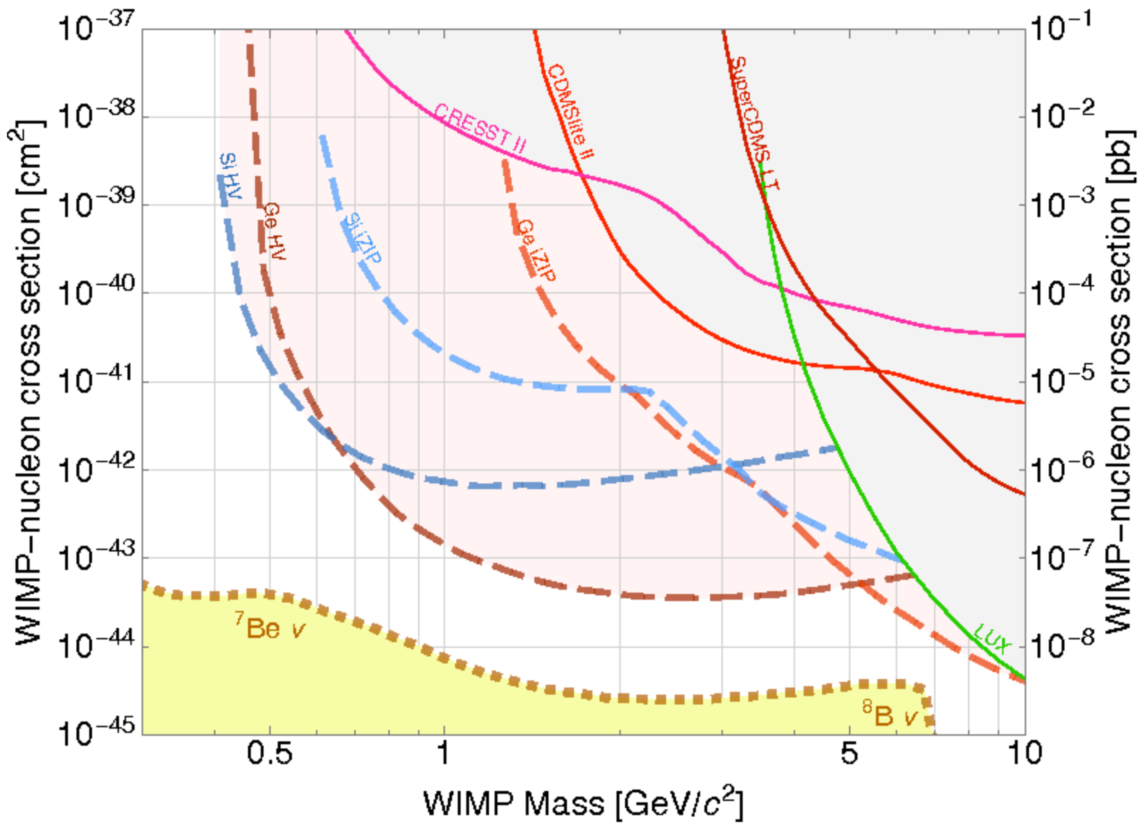
[Stan Yen]

Very Light Dark Matter

- Most DM direct detection experiments lose sensitivity for mDM below about 10 GeV.

$$E_{recoil} \lesssim 10\,\mathrm{keV}\left(\frac{m_{DM}}{10\,\mathrm{GeV}}\right)$$

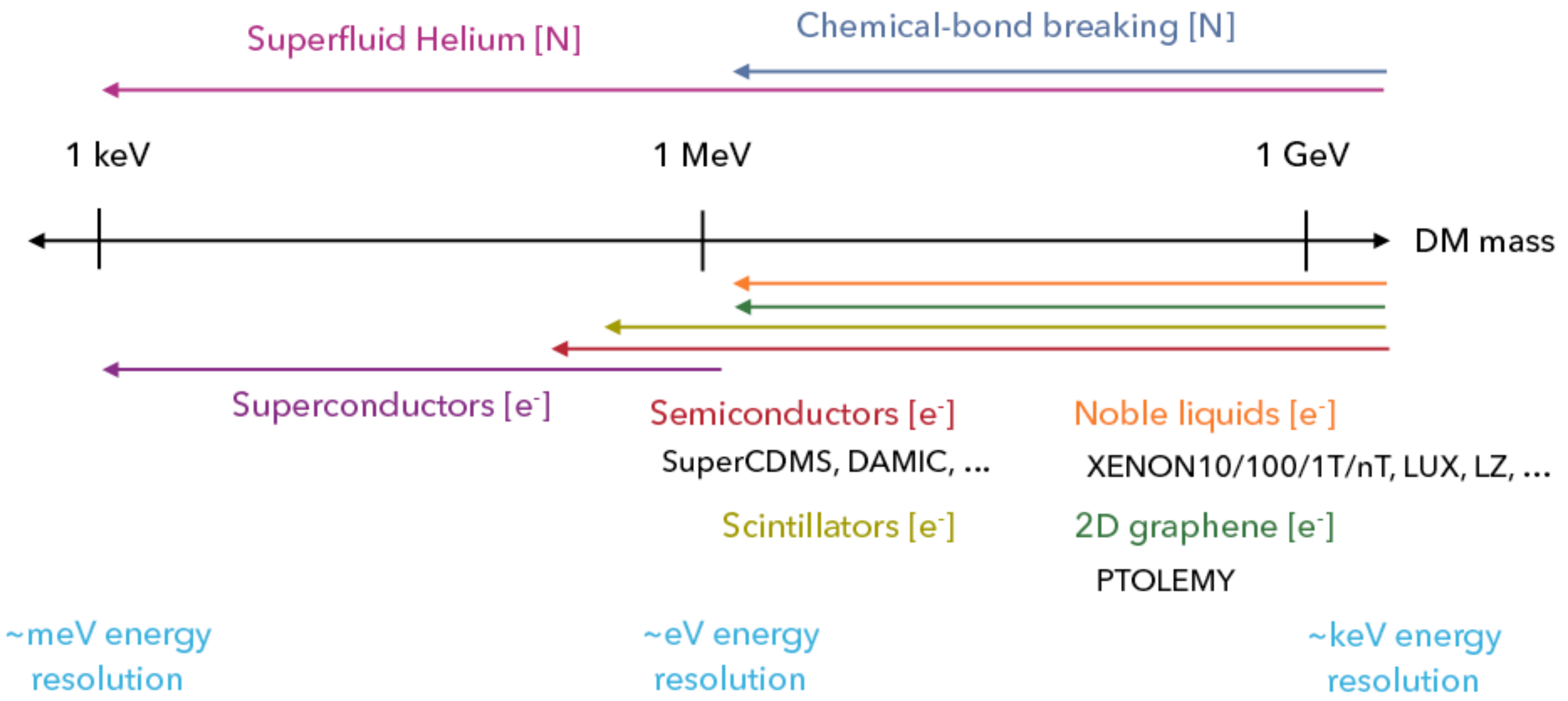
- SuperCDMS:



- Thermal DM can be as light at 5 keV, non-thermal even lighter!

Very Light Dark Matter

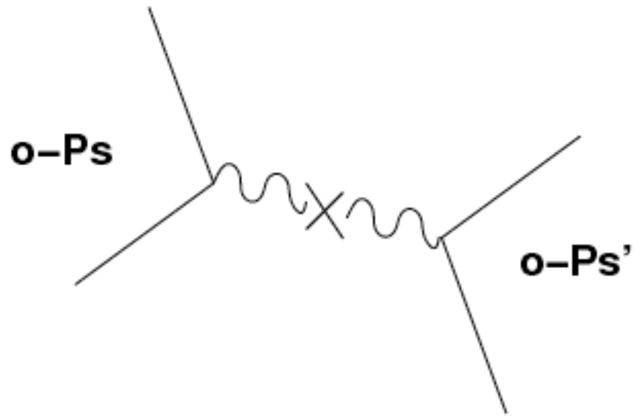
- Sub-GeV DM searches need new detector technologies:

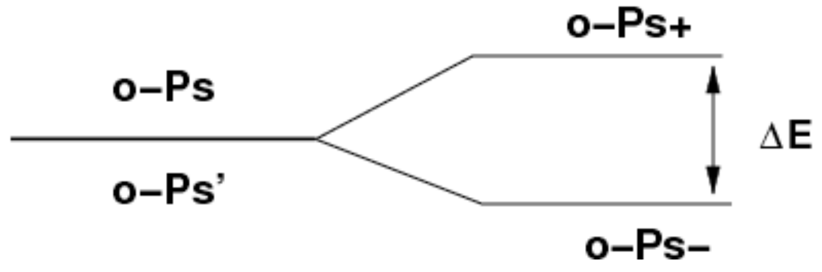


[Alexander *et al.*, Dark Sectors Community Report 2016]

Positronium (Muonium?)

- ARIEL (or cyclotron) could potentially make lots of positrons! Use to make positronium.
- Applications: [Makoto Fujiwara]
  - precision spectroscopy of positronium
  - test higher orders of QED through multi-photon decays
  - search for rare dark photon decays
  - test mixing with mirror positronium in mirror world scenarios





[Crivelli *et al.* 2010]

Sterile Neutrinos

- LSND and Ga anomalies suggest a new neutrino mass scale near 1eV corresponding to oscillations over short distances.

$$\Delta\,(\text{phase}) \;\sim\; \left(\frac{\Delta m^2}{\text{eV}^2}\right)\left(\frac{L}{1\,\text{m}}\right)\left(\frac{1\,\text{MeV}}{E}\right)$$

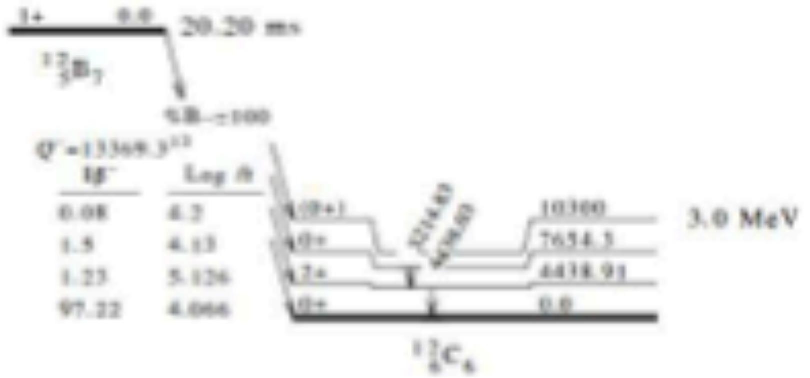
$$\Delta m^2_{atm} \;\simeq\; 2.5\times 10^{-3}\,\text{eV}^2 \qquad\qquad \Delta m^2_{sol} \;\simeq\; 7.4\times 10^{-5}\,\text{eV}^2$$

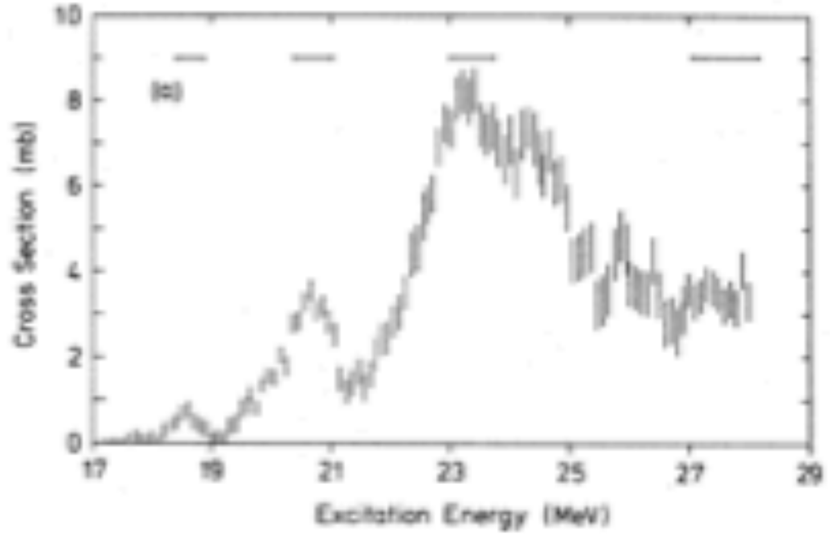
- Minimal 3+1 approach: 3 SM-like neutrinos, 1 “sterile” neutrino.

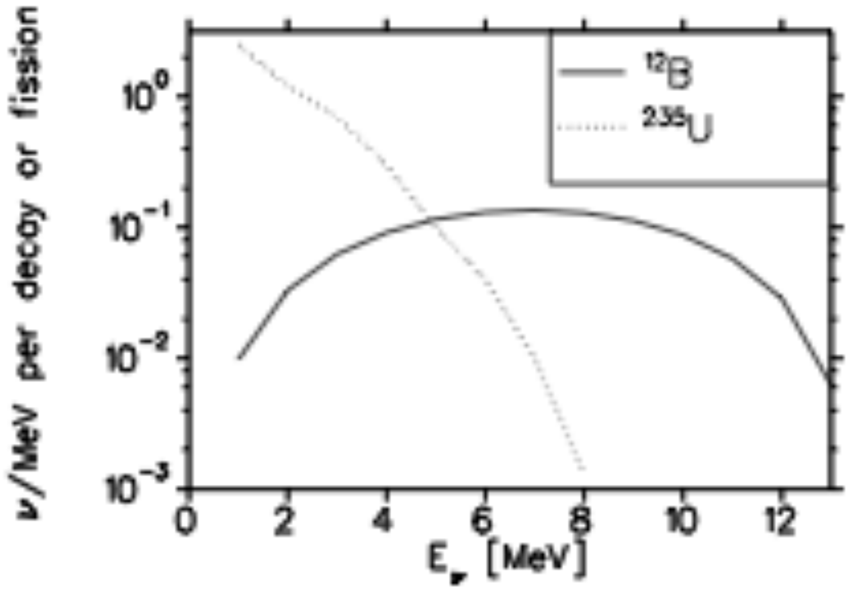
- Idea: search for short distance oscillations within detector using neutrinos from ^{12}B decays after production in ARIEL. (Similar to IsoDAR proposal based on ^{8}Li.) [John Behr]

TRIUMF In-target ν source with e-linac

ISOL extract 10% at best
→ in-target
$^{13}C(\gamma,p)^{12}B$
$t_{1/2}$: chop 20 ms to exclude prompt bkg

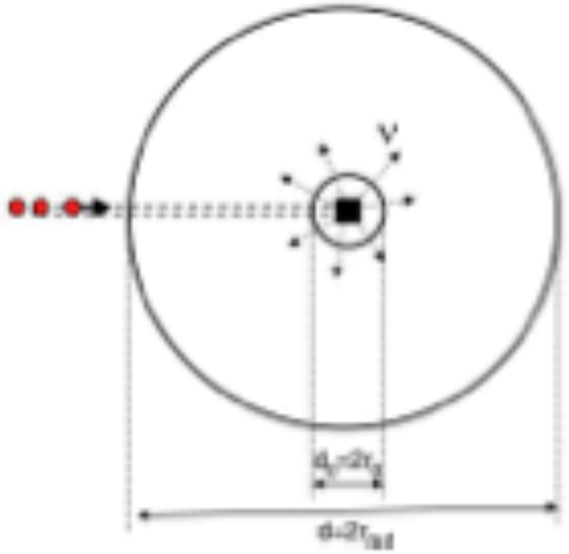






5×10^{-4} ^{12}B /e−
ISODAR 2×10^{-3} ^{8}Li /p
(ISODAR 7Li blanket → 10x)
35 MeV e^- 3 mA →
3×10^{13} $\bar{\nu}$/s
50 MeV e^- 15 mA →
3×10^{14} $\bar{\nu}$/s

Espinoza, Lazauskas, Volpe PRD (2012)



20 ton

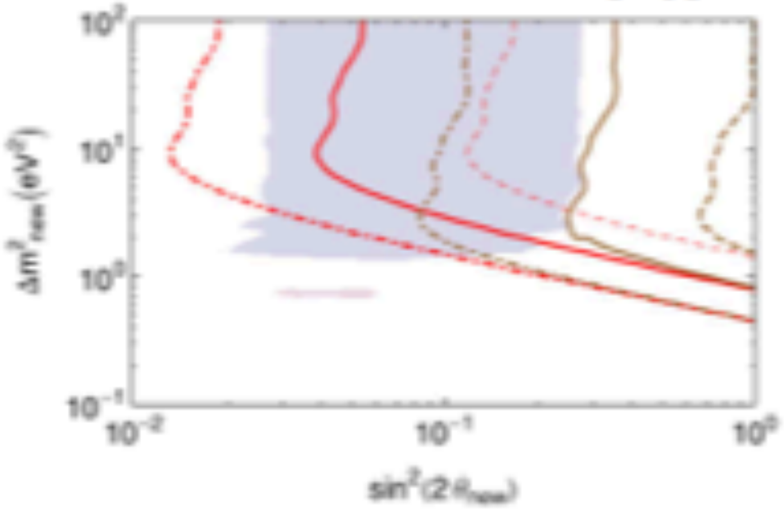


FIG. 6 (color online). Exclusion plots with binned analysis of the simulated data, obtained by varying the ion intensity: 10^{14} ions/s (dash-dotted), 10^{13} ions/s (solid), and 10^{12} ions/s

[John Behr - Monday]

Precision Higgs Measurements

- Understanding the Higgs boson is key to elementary particles!
- The Higgs portal opportunity:

1. Small decay width:

$$\Gamma(h_{SM}) \;=\; 4.1\,\mathrm{MeV} \;\simeq\; (3\times 10^{-5})m_h$$

⇒ new decay modes can have significant branching ratios

2. Lowest dimension gauge-invariant operator:

$$\mathcal{L}_{eff} \supset (\mathrm{BSM})|H|^2$$

⇒ less suppressed compared to other connectors to BSM

- Rare Higgs decays realize this opportunity!

Precision Higgs Measurements

- Understanding the Higgs boson is key to elementary particles!
- Number of Higgs bosons produced: [Gori 2016]
  - LHC: 1.5×10^7 $\left\{ \begin{matrix} 300\,\mathrm{fb}^{-1} \\ 14\,\mathrm{TeV} \end{matrix} \right\}$

    1.5×10^8 $\left\{ \begin{matrix} 3000\,\mathrm{fb}^{-1} \\ 14\,\mathrm{TeV} \end{matrix} \right\}$
  - ILC: 3×10^5 $\left\{ \begin{matrix} 500\,\mathrm{fb}^{-1} \\ 500\,\mathrm{GeV} \end{matrix} \right\} \oplus \left\{ \begin{matrix} 200\,\mathrm{fb}^{-1} \\ 350\,\mathrm{GeV} \end{matrix} \right\} \oplus \left\{ \begin{matrix} 500\,\mathrm{fb}^{-1} \\ 250\,\mathrm{GeV} \end{matrix} \right\}$

    2×10^6 $\left\{ \begin{matrix} 4000\,\mathrm{fb}^{-1} \\ 500\,\mathrm{GeV} \end{matrix} \right\} \oplus \left\{ \begin{matrix} 200\,\mathrm{fb}^{-1} \\ 350\,\mathrm{GeV} \end{matrix} \right\} \oplus \left\{ \begin{matrix} 2000\,\mathrm{fb}^{-1} \\ 250\,\mathrm{GeV} \end{matrix} \right\}$
- LHC better for very clean channels, ILC better for others.

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Thank you!
Merci!

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