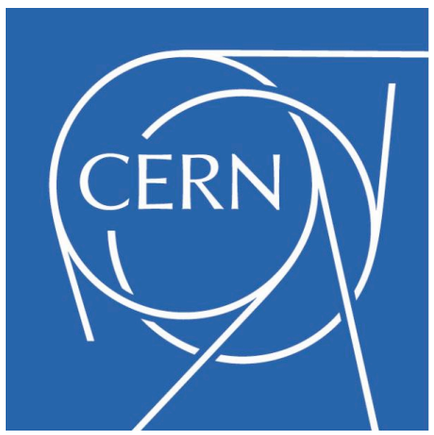
Beyond and Below The Standard Model: Exotic Light New Physics

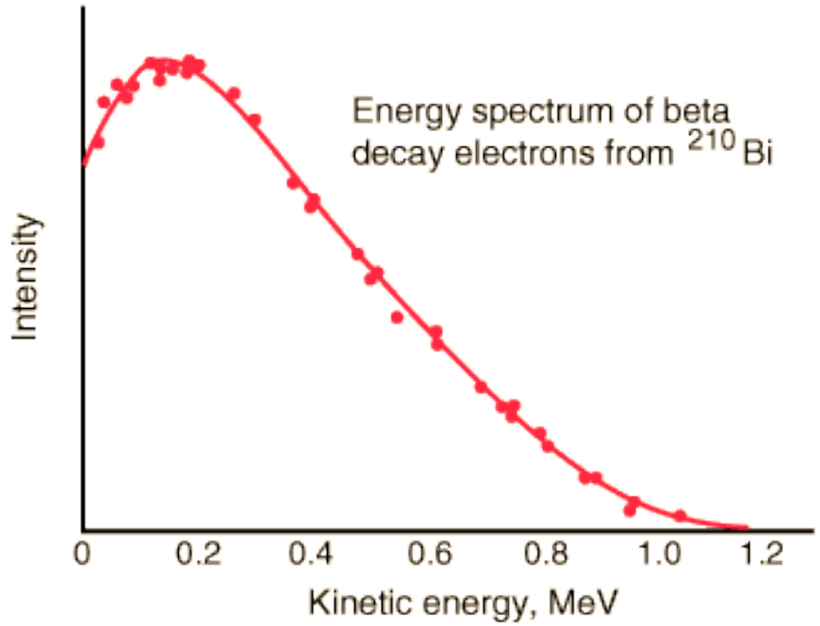
Brian Batell
CERN



La Thuile 2015 - Les Rencontres de Physique de la Vallée d'Aoste
March 2, 2015

History lesson - 1930s:

- Back then, the "Standard Model" was photon, electron, nucleons
- Beta decay: $n \to p + e^-$



Continuous spectrum!

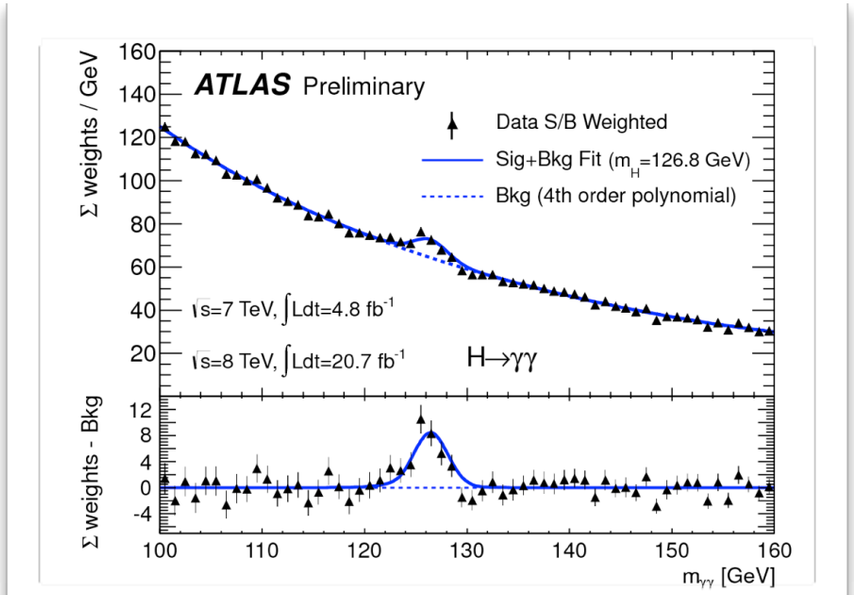
- Pauli proposes a radical solution - the neutrino!

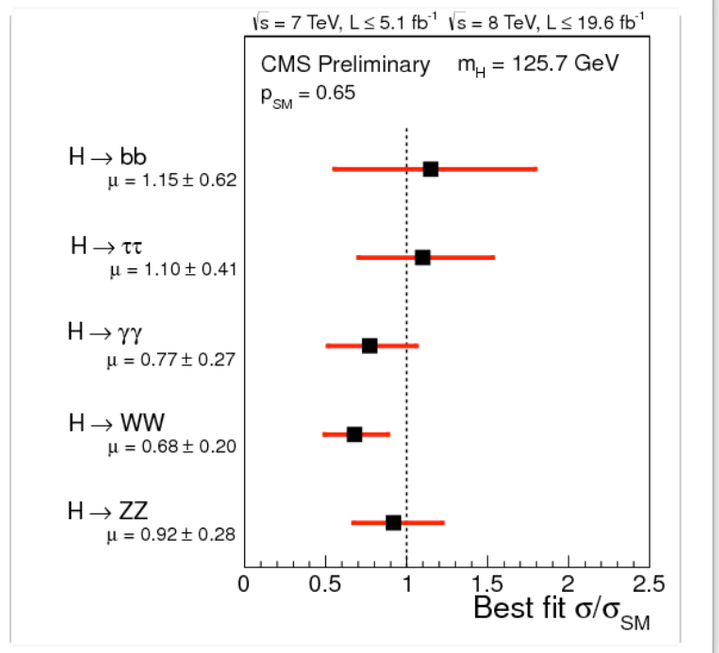
$$n \to p + e^- + \bar{\nu}$$

- Perfect example of a "hidden sector"
  - neutrino is electrically neutral (QED gauge singlet)
  - very weakly interacting and light
  - interacts with "Standard Model" through "portal" - $(\bar{p}\gamma^\mu n)(\bar{e}\gamma_\mu \nu)$

Today, 2015 - Where are we?

- Higgs!
- Triumph of the Standard Model!



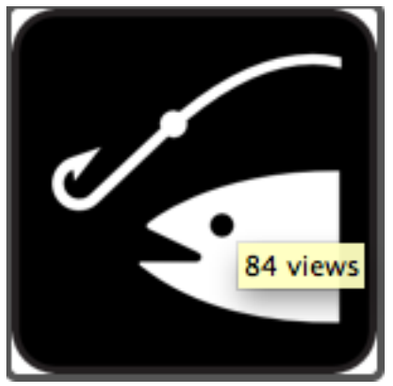


- Still, many reasons to believe there is new physics

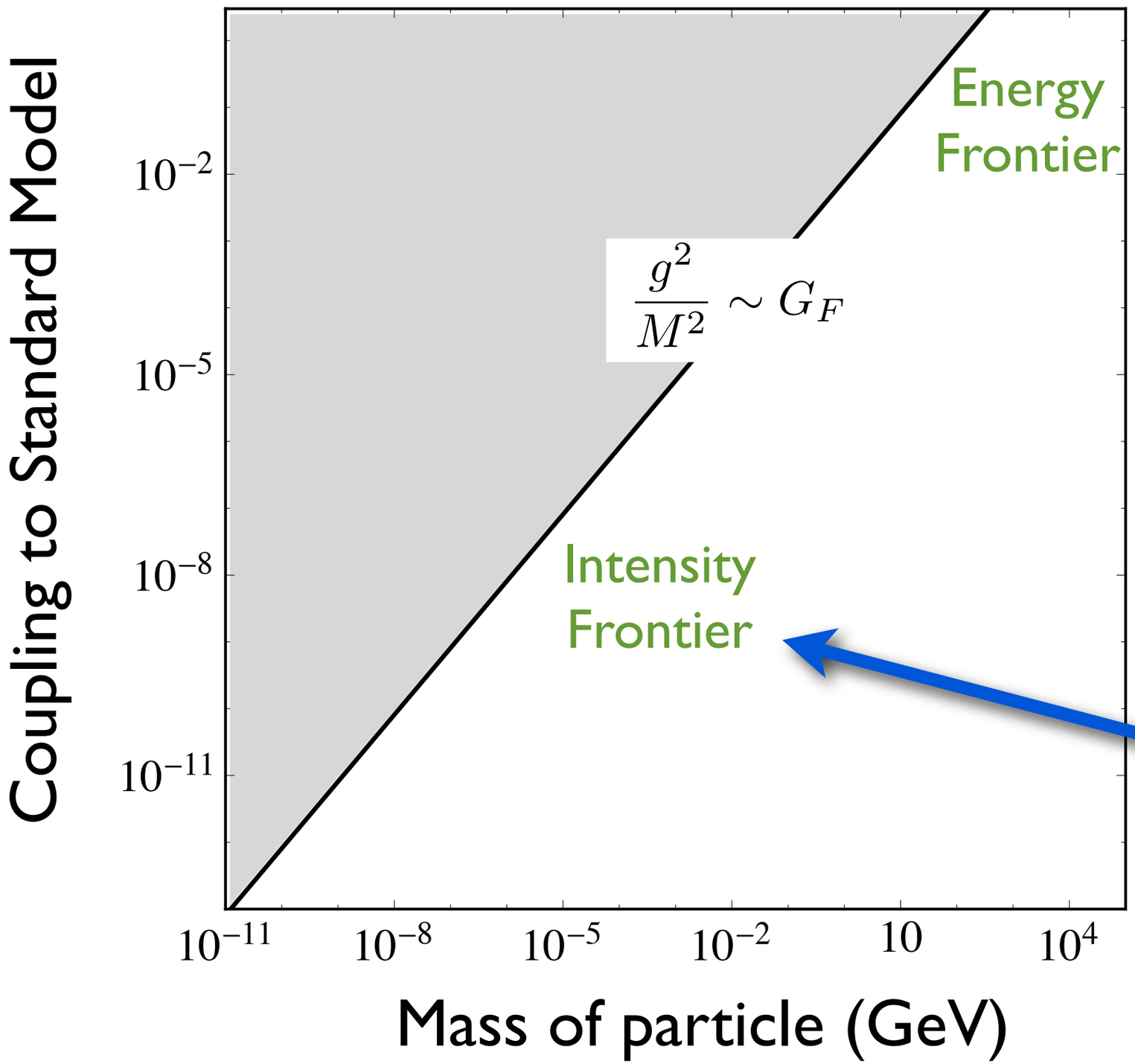
Theoretical: Naturalness (Higgs, CC), Flavor, Strong CP, Unification, Gravity ...

Empirical: Dark Matter, Neutrino Oscillations, Baryon Asymmetry

- Unfortunately, there are no guarantees of discovery
- All searches for new physics are now fishing expeditions



Where is the New Physics?



EWSB, Naturalness
WIMP DM ...

RH neutrinos
Axion
Dark Matter
Hidden sector
...

The Scale of New Physics

Theoretical hints (naturalness) - unambiguously points towards new scale

Hierarchy problem → $v \sim 100\,\mathrm{GeV}$

Cosmological Constant → $\rho_{\mathrm{vac}}^{1/4} \sim 10^{-3}\,\mathrm{eV} \quad (m_\nu \sim 0.1\,\mathrm{eV})$

Empirical hints - no firm prediction for the new physics scale!

Matter-Antimatter Asymmetry → ?

Dark Matter → ?

Neutrino mass → ?

We must search High and Low for New Physics!

Light, Exotic, and Motivated

Lensing, rotation curves, structure, CMB... → Dark Matter

Neutrino oscillations → Right Handed Neutrinos

Strong CP → Axion

Supersymmetry → Gravitino
SUSY hidden sectors

...

Portals - an EFT approach

$$LHN \qquad \text{Neutrino portal}$$

$$(\mu S + \lambda S^2) H^\dagger H \qquad \text{Higgs Portal}$$

$$-\frac{\kappa}{2} B_{\mu\nu} V^{\mu\nu} \qquad \text{Vector Portal}$$

- Only three renormalizable portals - can be generated at a high scale
- Respect approximate symmetries of the Standard Model
  - Flavor, Parity, CP - allows for relatively large couplings to be viable

Portals - an EFT approach

LHN Neutrino portal

$(\mu S + \lambda S^2) H^\dagger H$ Higgs Portal

Focus on vector portal in this talk

$-\frac{\kappa}{2} B_{\mu\nu} V^{\mu\nu}$ Vector Portal

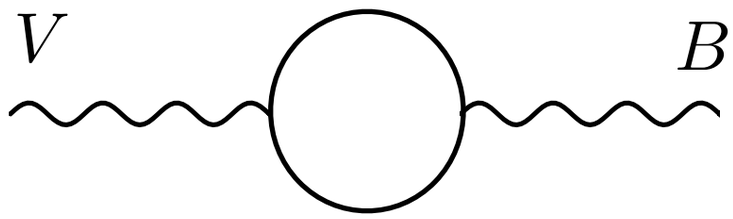
- Only three renormalizable portals - can be generated at a high scale
- Respect approximate symmetries of the Standard Model
  - Flavor, Parity, CP - allows for relatively large couplings to be viable

Vector Portal

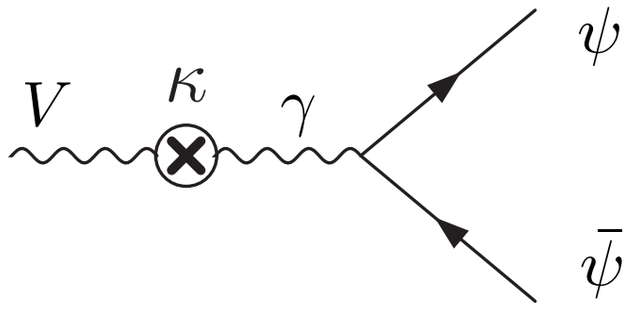
$$-\frac{\kappa}{2} B_{\mu\nu} V^{\mu\nu}$$

Holdom

Mixing parameter can be generated radiatively at one or more loops; expected size ~ 10^{-3} or smaller



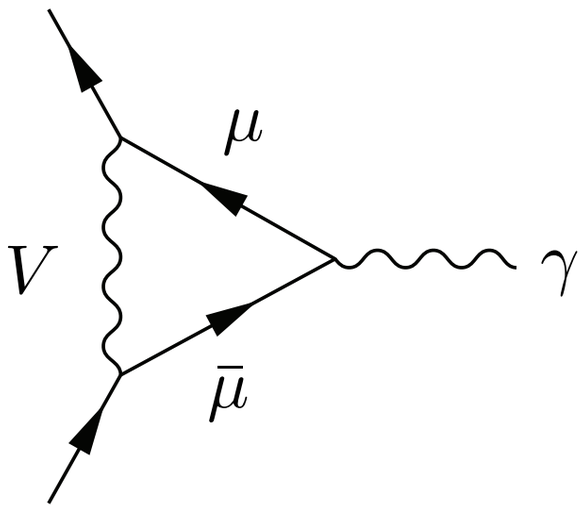
If dark U(1) is broken visible matter picks up a milli-dark charge.

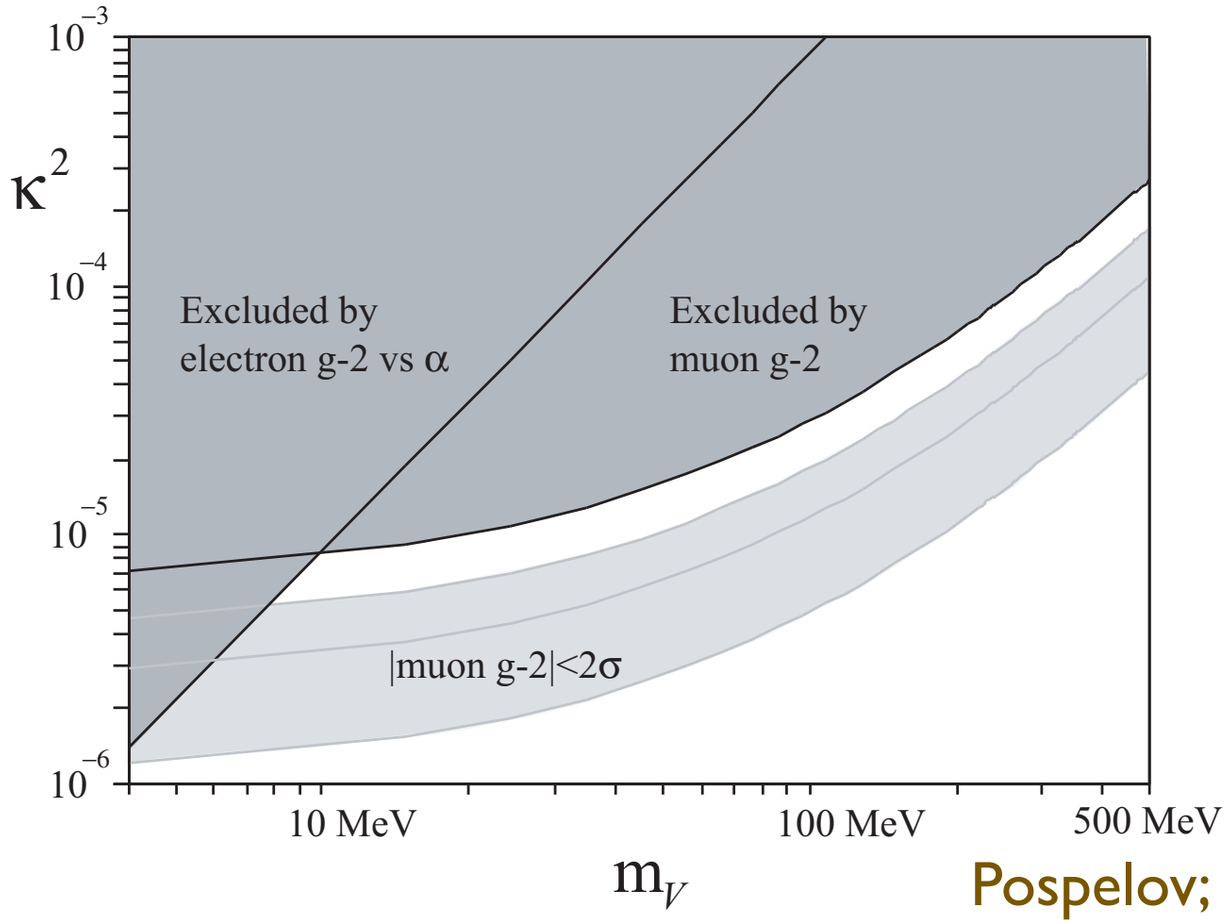


$$\mathcal{L} \supset \kappa V_\mu [-c_w J^\mu_{EM} + s_w (1 - m_Z^2/m_V^2)^{-1} J^\mu_Z].$$

Vector portal often motivated by anomalies:

Example: Muon Anomalous Magnetic Moment (~ 3σ)

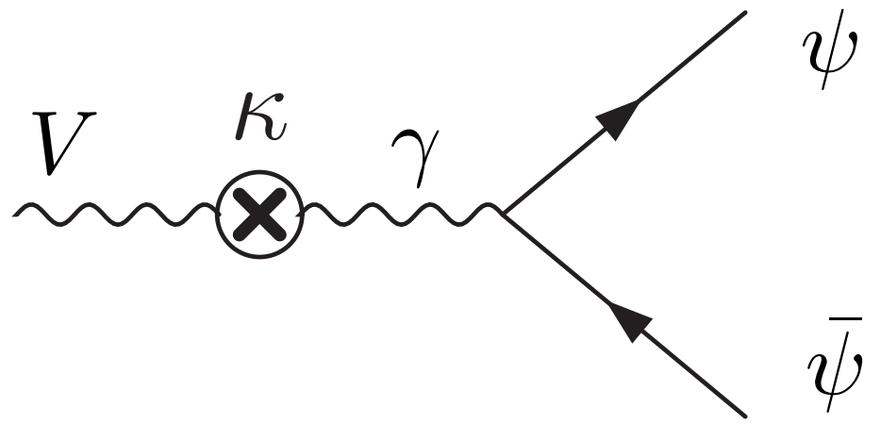


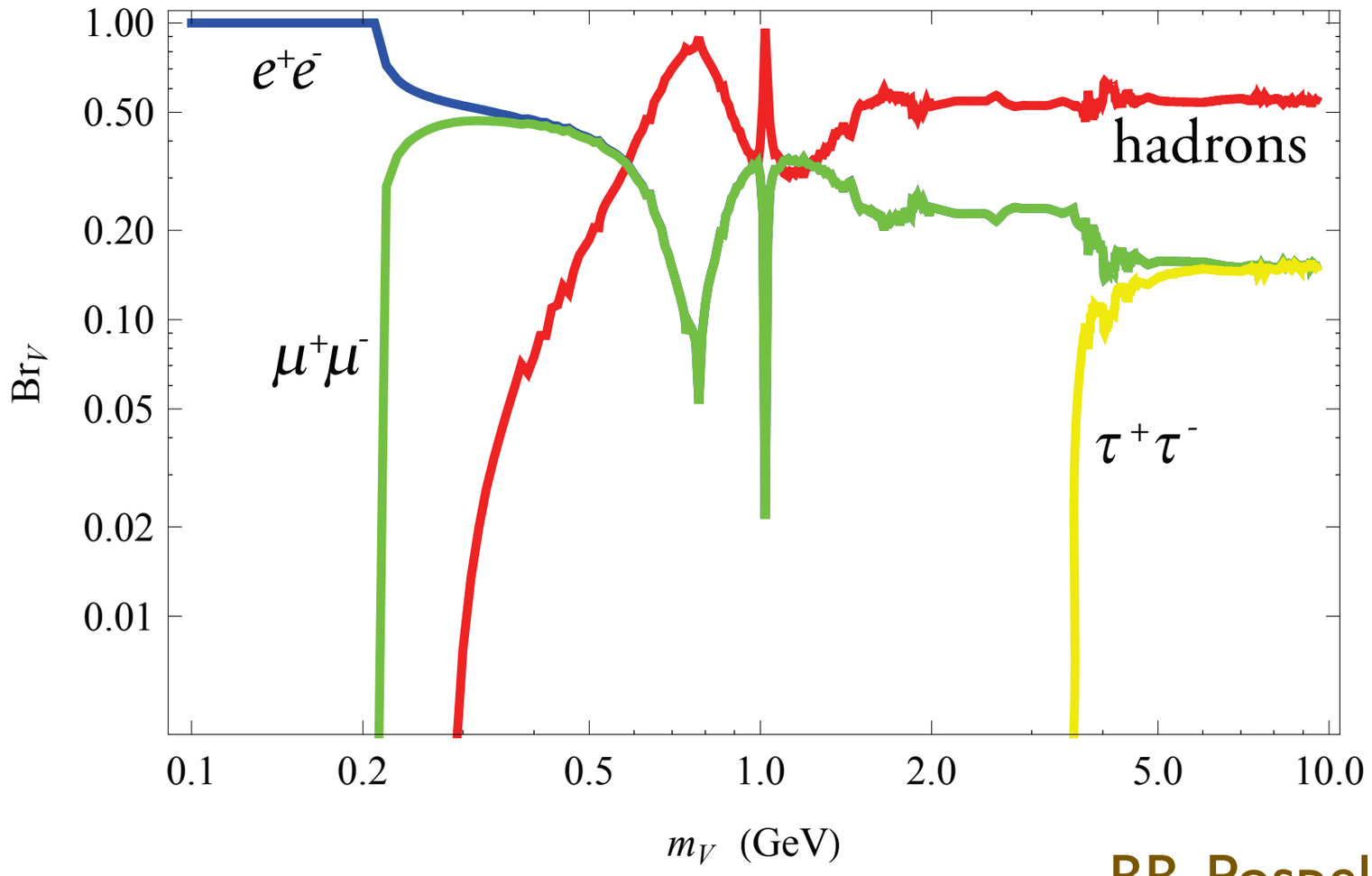


Pospelov; Bohm, Fayet

Dark photon decays

- governed by EM form factor
- significant branching to leptons

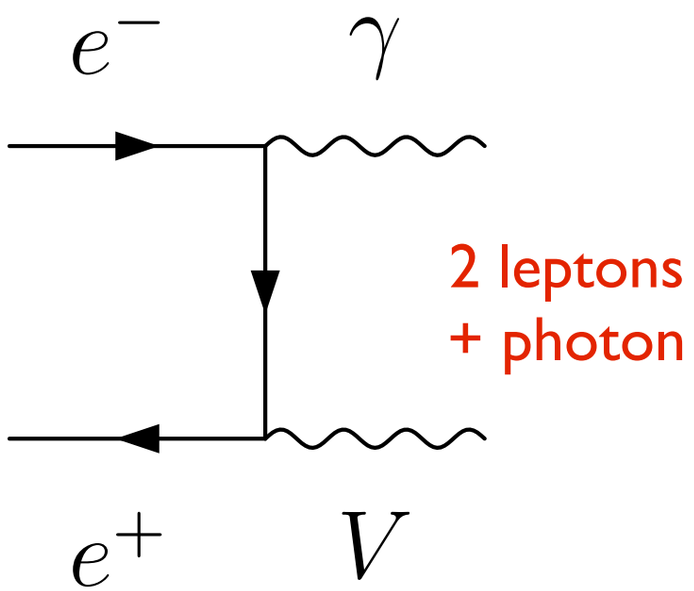




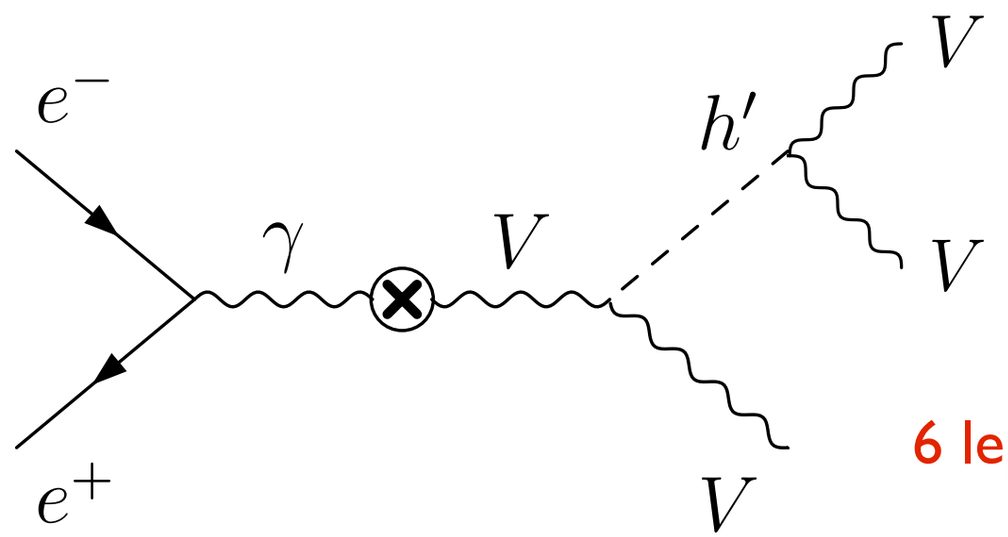
BB, Pospelov, Ritz

Signatures at low-energy e^+e^- colliders

BB, Pospelov, Ritz;
Essig, Schuster, Toro;
Reece, Wang;

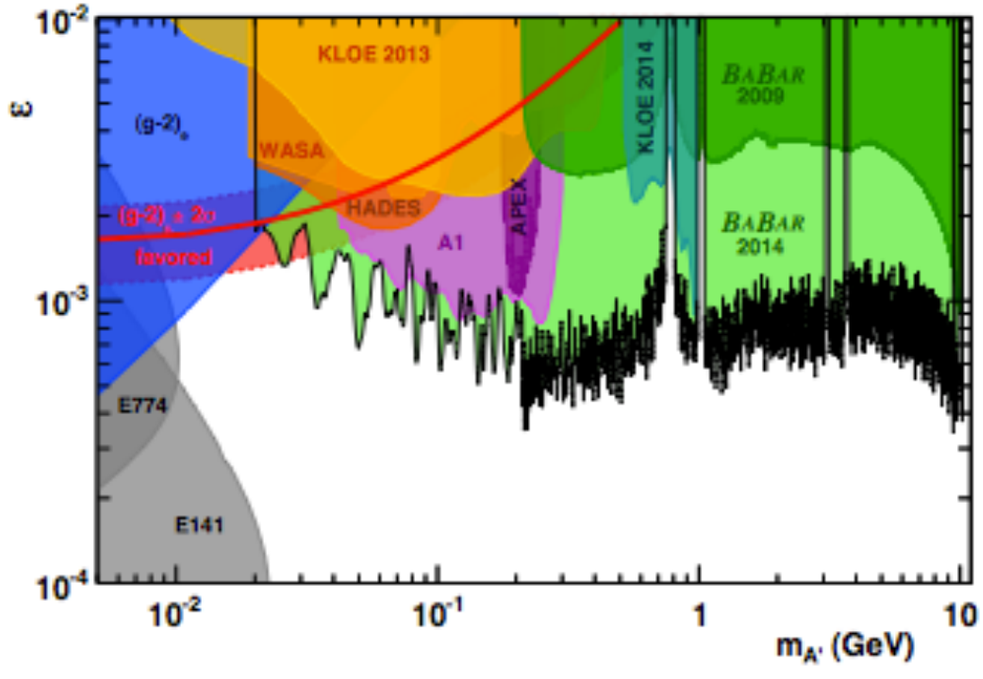


2 leptons
+ photon

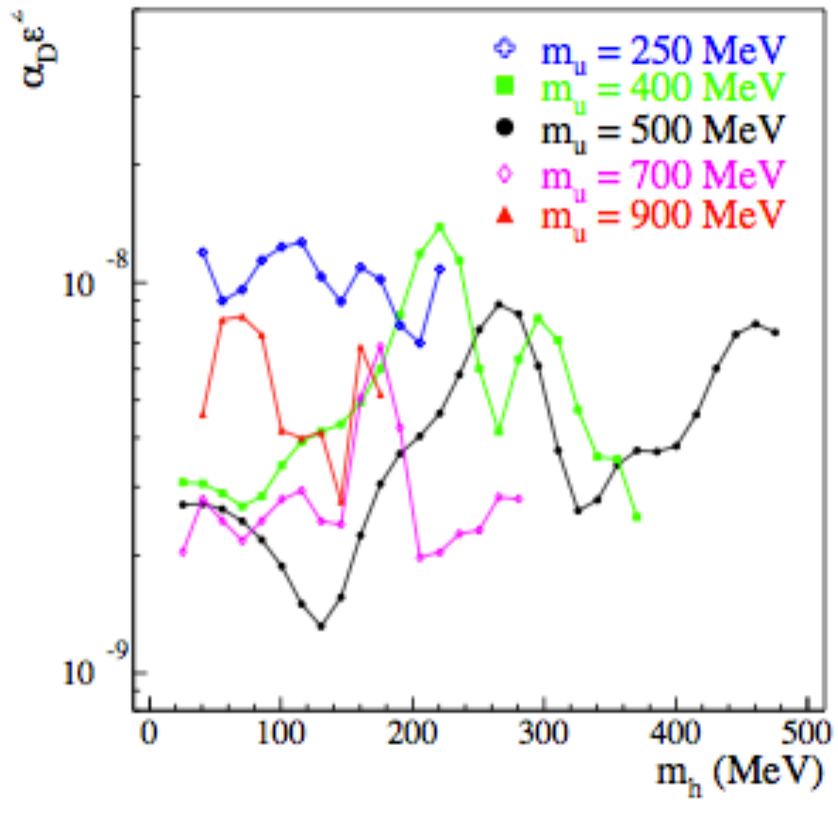


6 leptons

Dark photon searches:



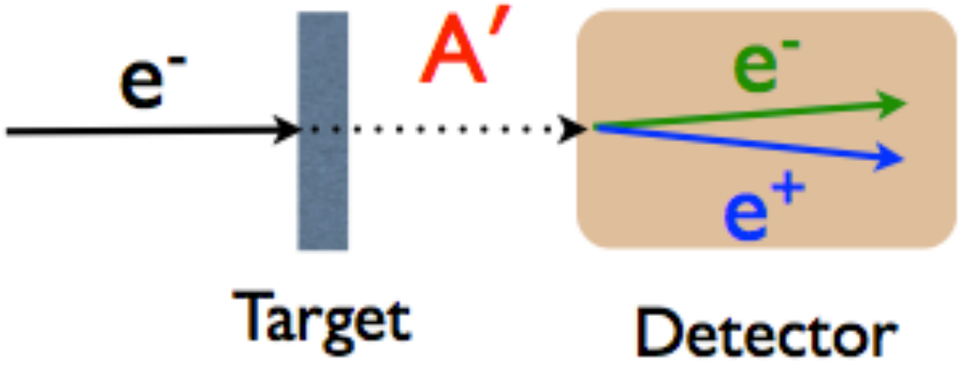
[BaBAR, PRL 113 (2014)]



[KLOE-2, arXiv:1501.06795]

Signatures at high intensity fixed target experiments

Bjorken et al;,
Andreas et al;
and others



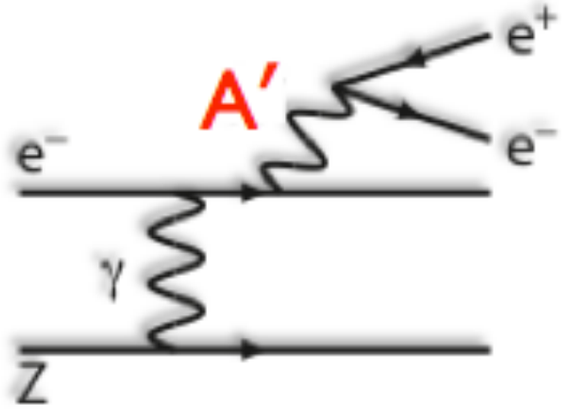
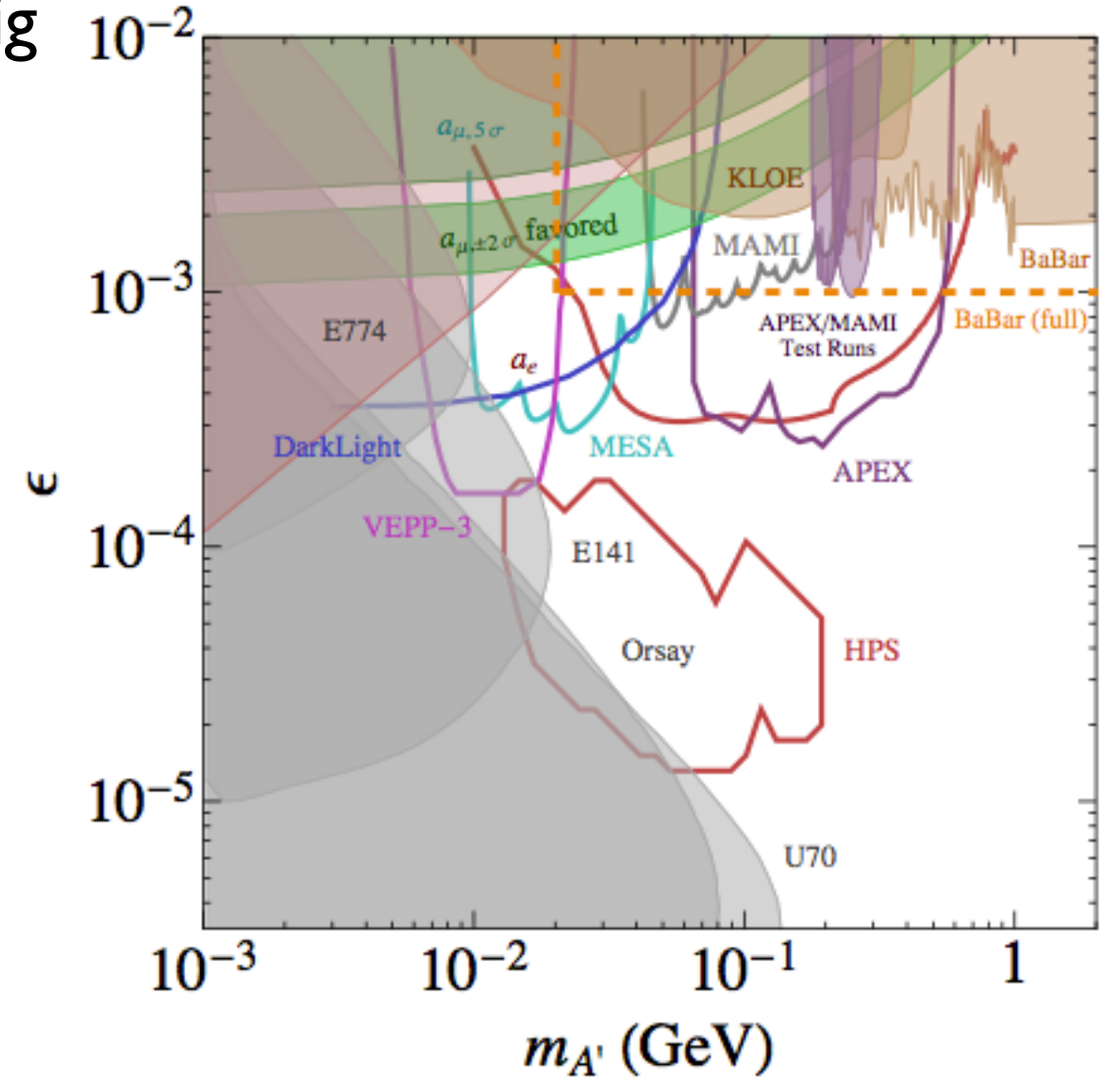


Fig. from R. Essig

- Look for a resonance or displaced vertex

- Current/planned experiments (APEX,HPS,MAMI,DarkLight, VEPP-3, MESA...) will cover a lot of new ground!

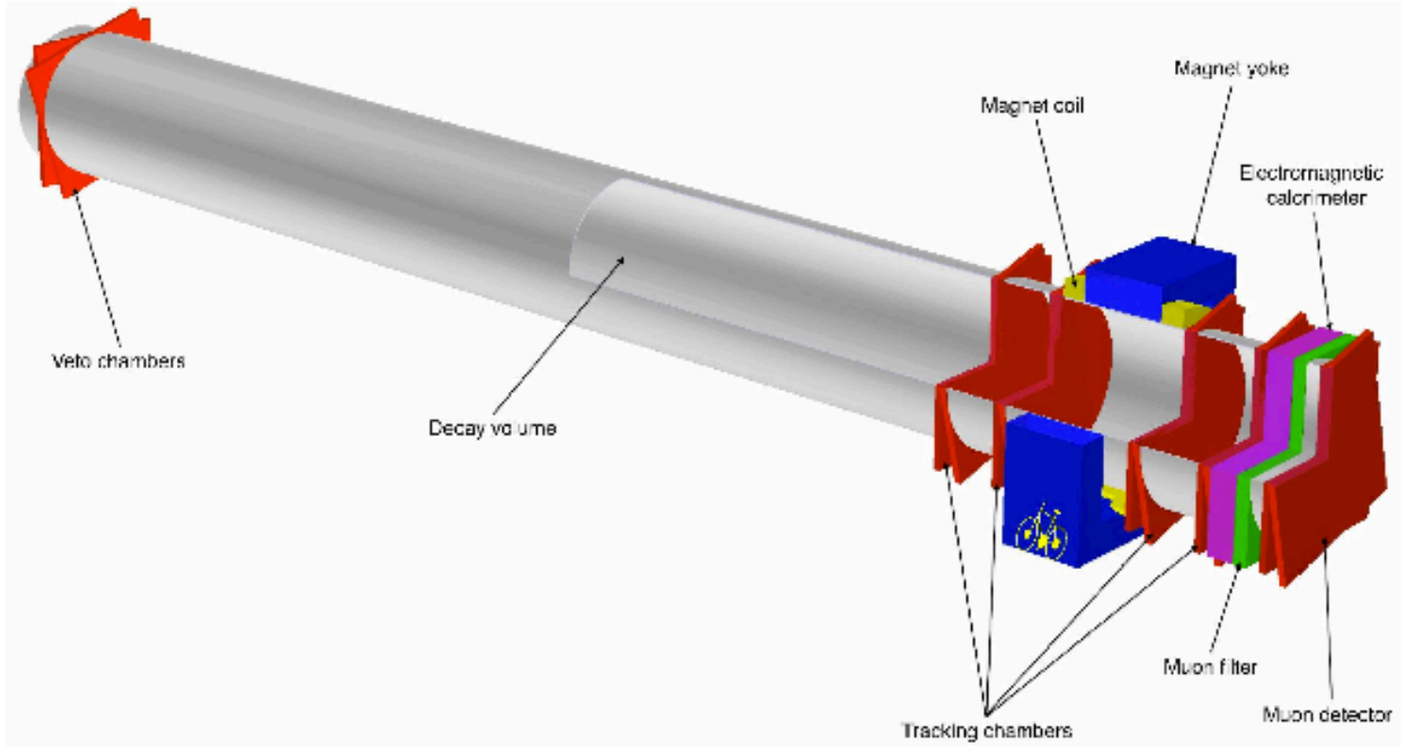


SHiP experiment (Search for Hidden Particles) http://www.cern.ch/ship

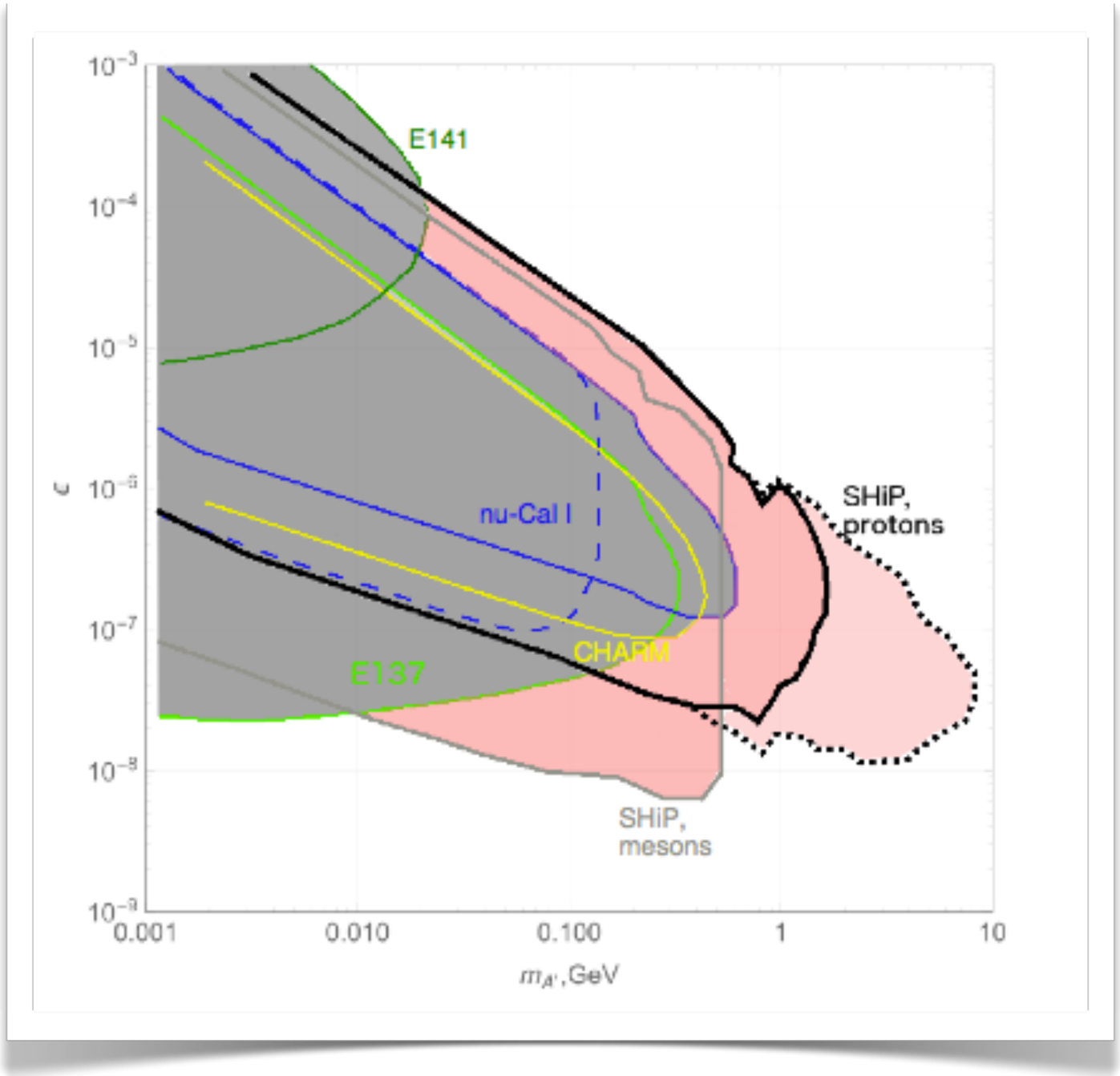
- New Fixed target facility proposed at CERN

- 400 GeV protons, ~10^{20} protons-on-target

- Powerful capability to search for weakly interacting, long-lived particles that decay visibly



SHiP sensitivity to dark photons



[Gorbunov, Makarov, Timiryasov, '14]

Unique sensitivity at high mass, and small mixing

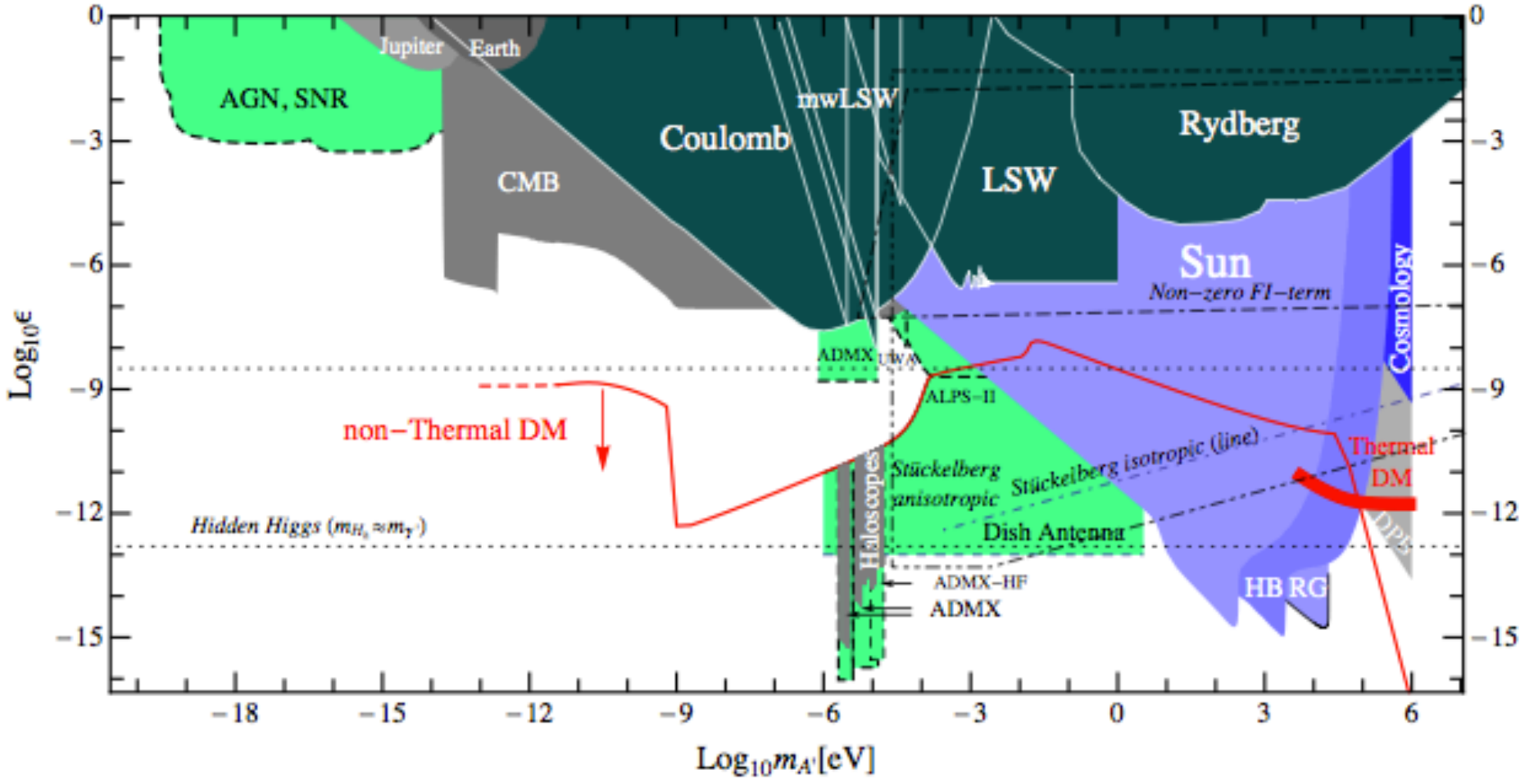
Summary of different channels

Generic decay modes	Final states	Models tested
meson and lepton	πl, Kl, ρl, $l = (e, \mu, \nu)$	ν portal, HNL, SUSY neutralino
two leptons	e^+e^-, $\mu^+\mu^-$	V, S and A portals, SUSY s-goldstino
two mesons	$\pi^+\pi^-$, K^+K^-	V, S and A portals, SUSY s-goldstino
3 body	$l^+l^-\nu$	HNL, SUSY neutralino

talk by M. Shaposhnikov
2nd SHiP collaboration meeting

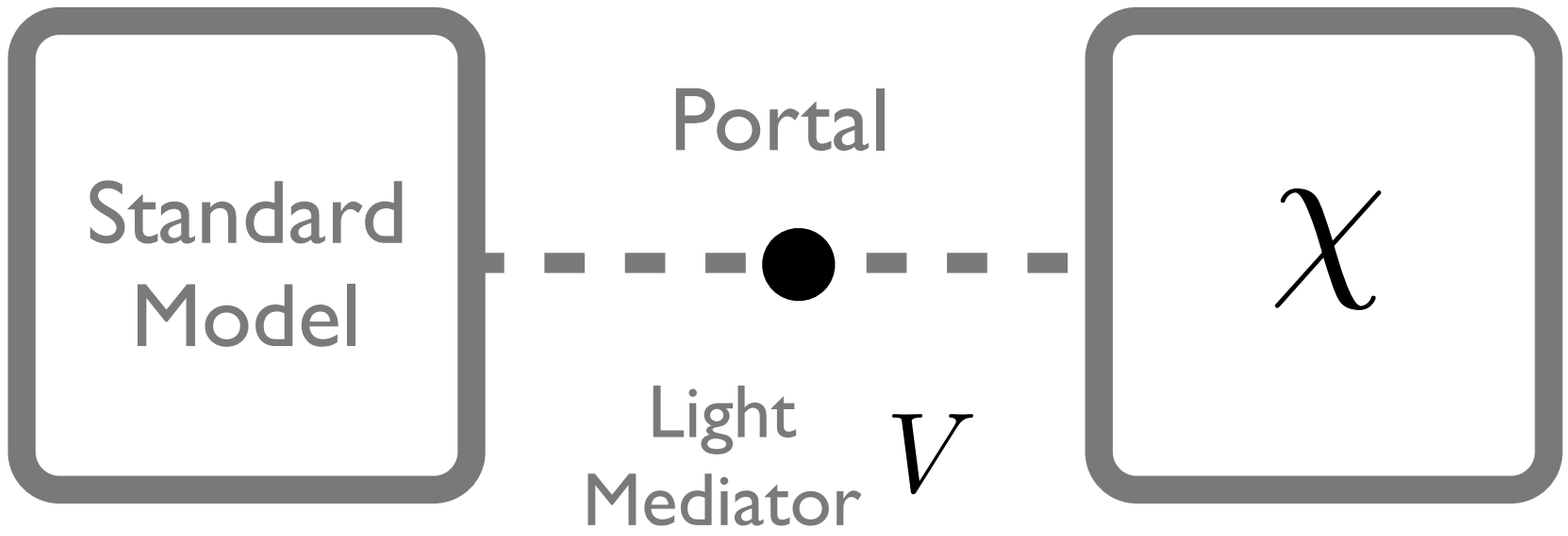
SHiP can search for a wide range of signatures probing a variety of portals & models!

The low energy frontier of the vector portal

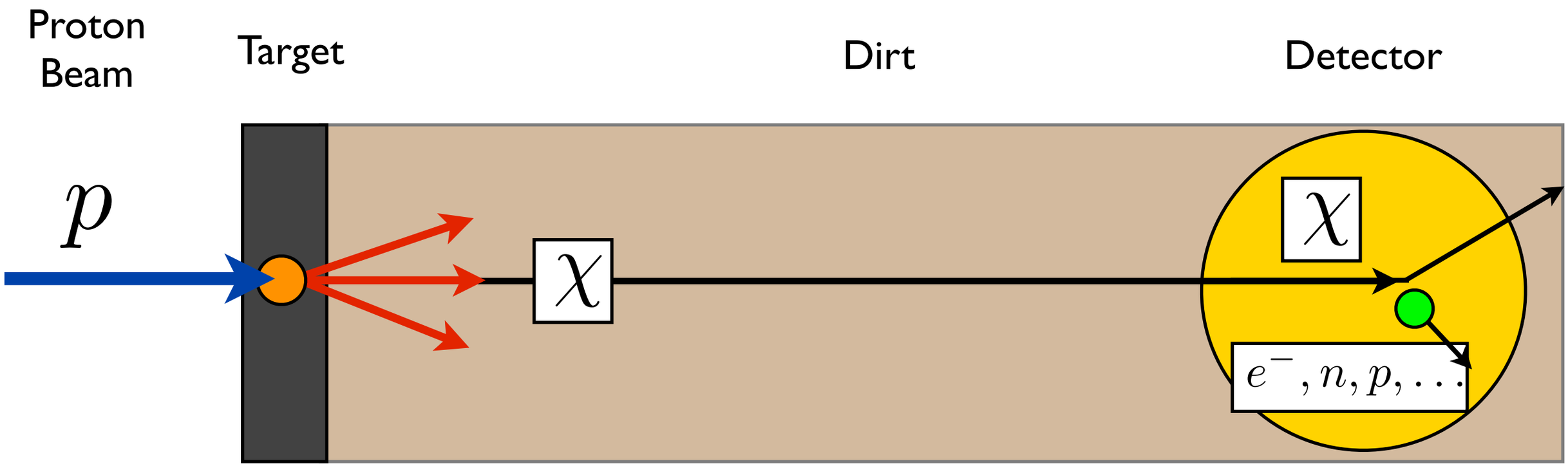


Jaeckel, Ringwald, Redondo...

Portal to Dark Matter



Relativistic Dark Matter Beam!



BB, Pospelov Ritz

- Superior sensitivity to light dark matter + light mediator

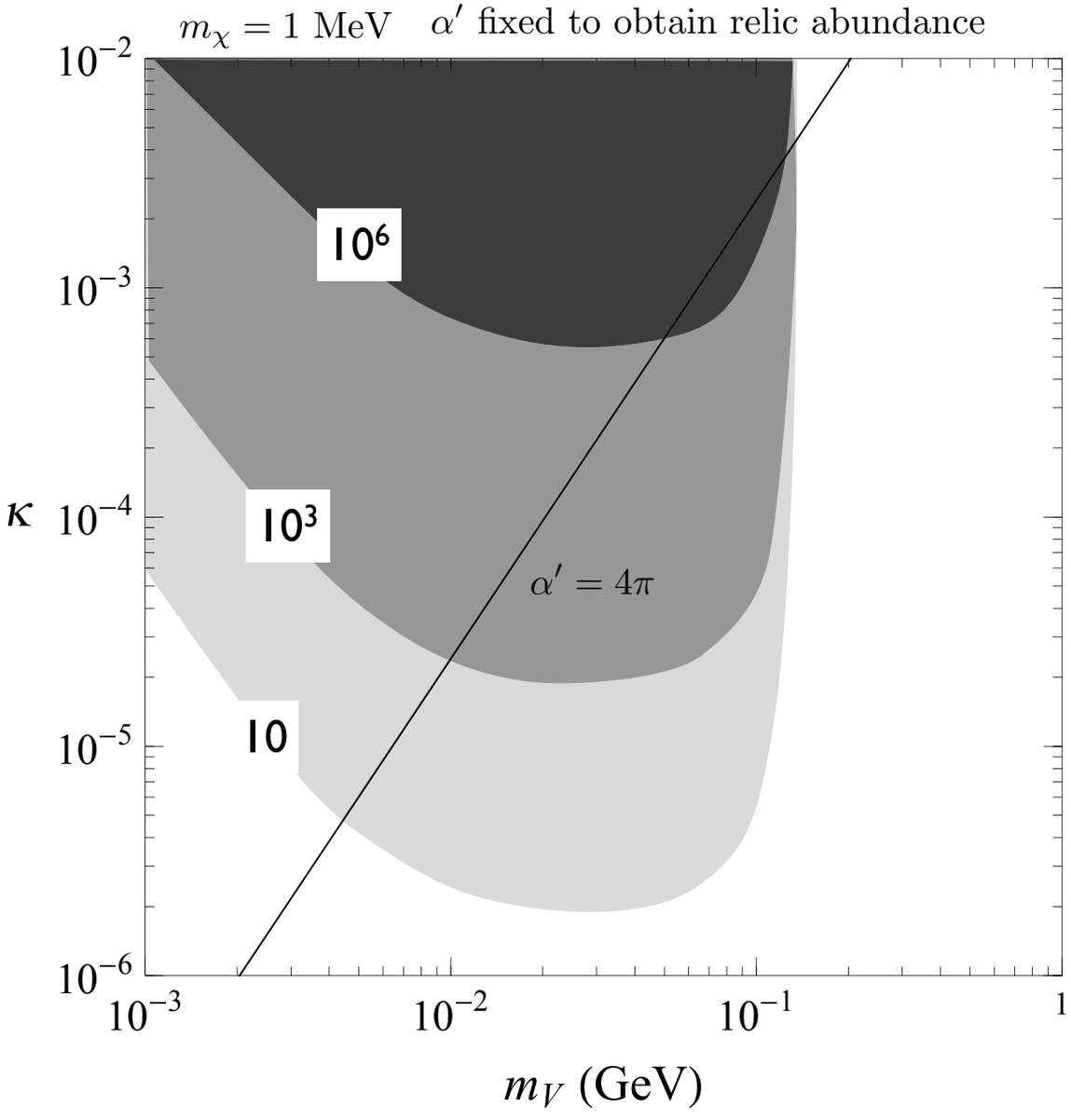
LSND

Production: $\pi^0 \to \gamma V \to \gamma \chi \bar{\chi}$

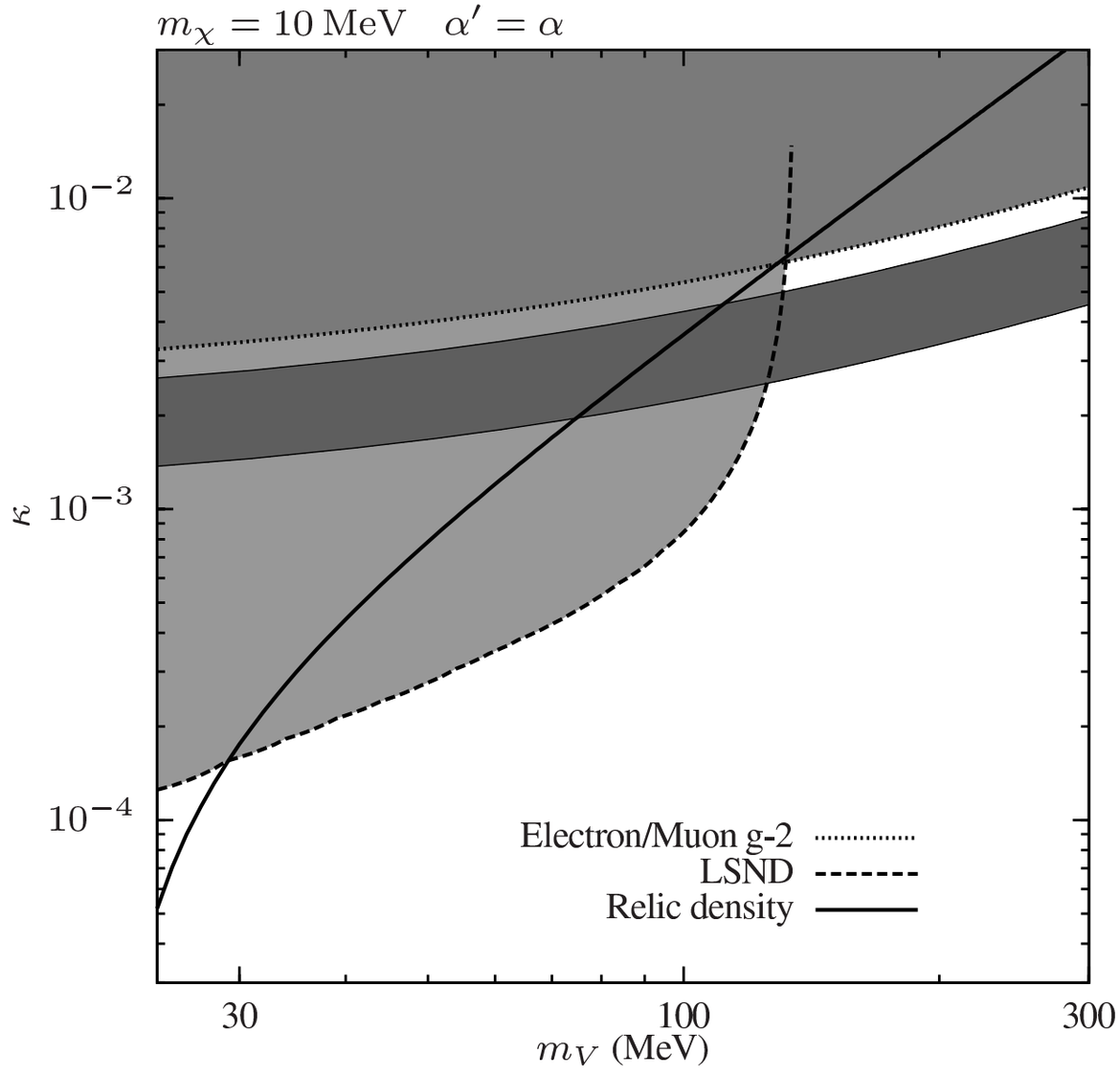
Sensitivity to $\chi e \to \chi e$

[Auerbach et al. (LSND Collaboration), '01]

- LAMPF, 800 MeV protons, ~ 10^{23} POT
- water / high Z target
- detector: 30m off axis from target, cylindrical, 170 tons mineral oil



BB, Pospelov, Ritz



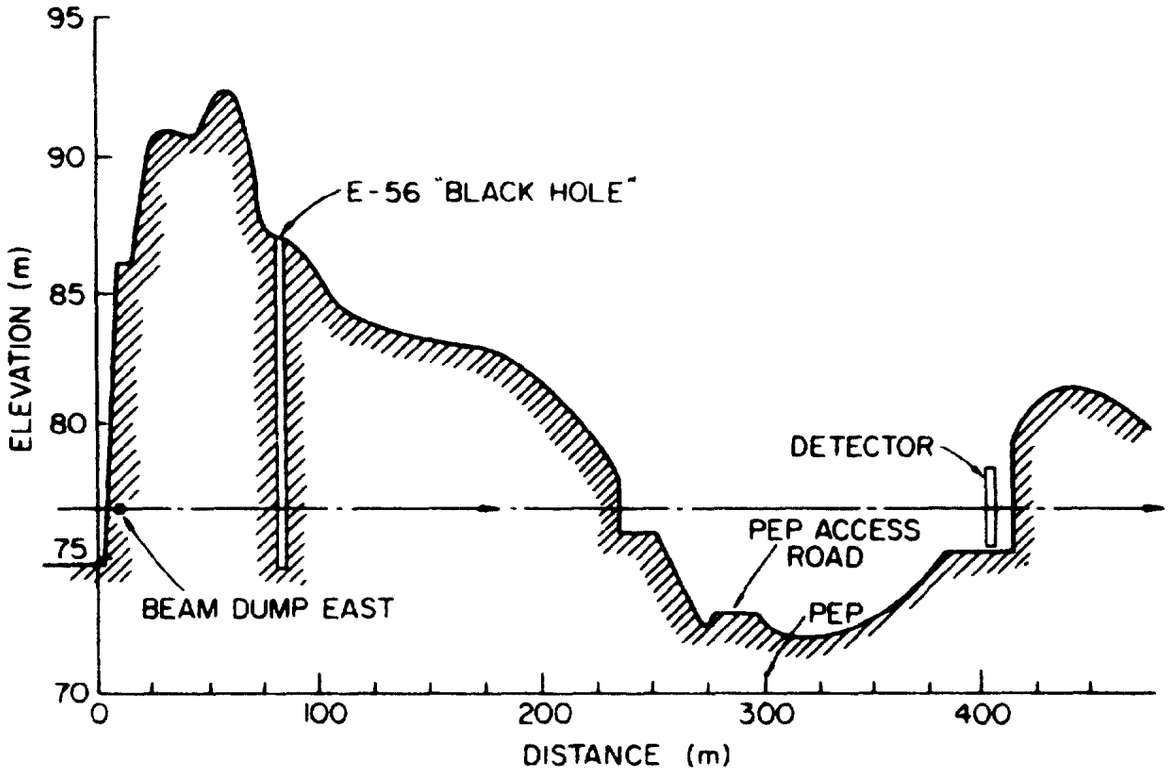
deNiverville, Pospelov, Ritz

SLAC E137

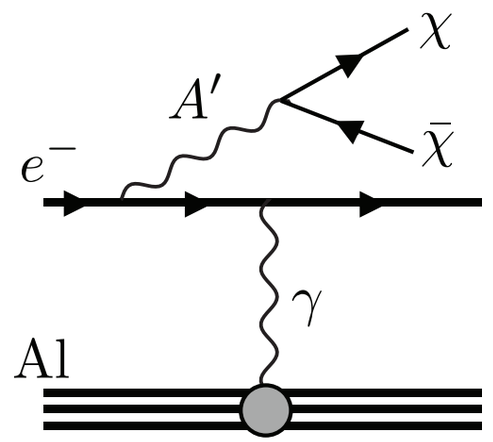
BB, Essig, Surujon

[Bjorken et al., (E137 Collaboration) '88]

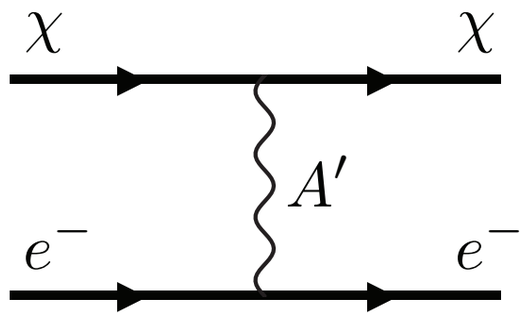
- 20 GeV electron beam; 30 C dumped;
- Aluminum target
- Shower calorimeter detector, 400m from dump



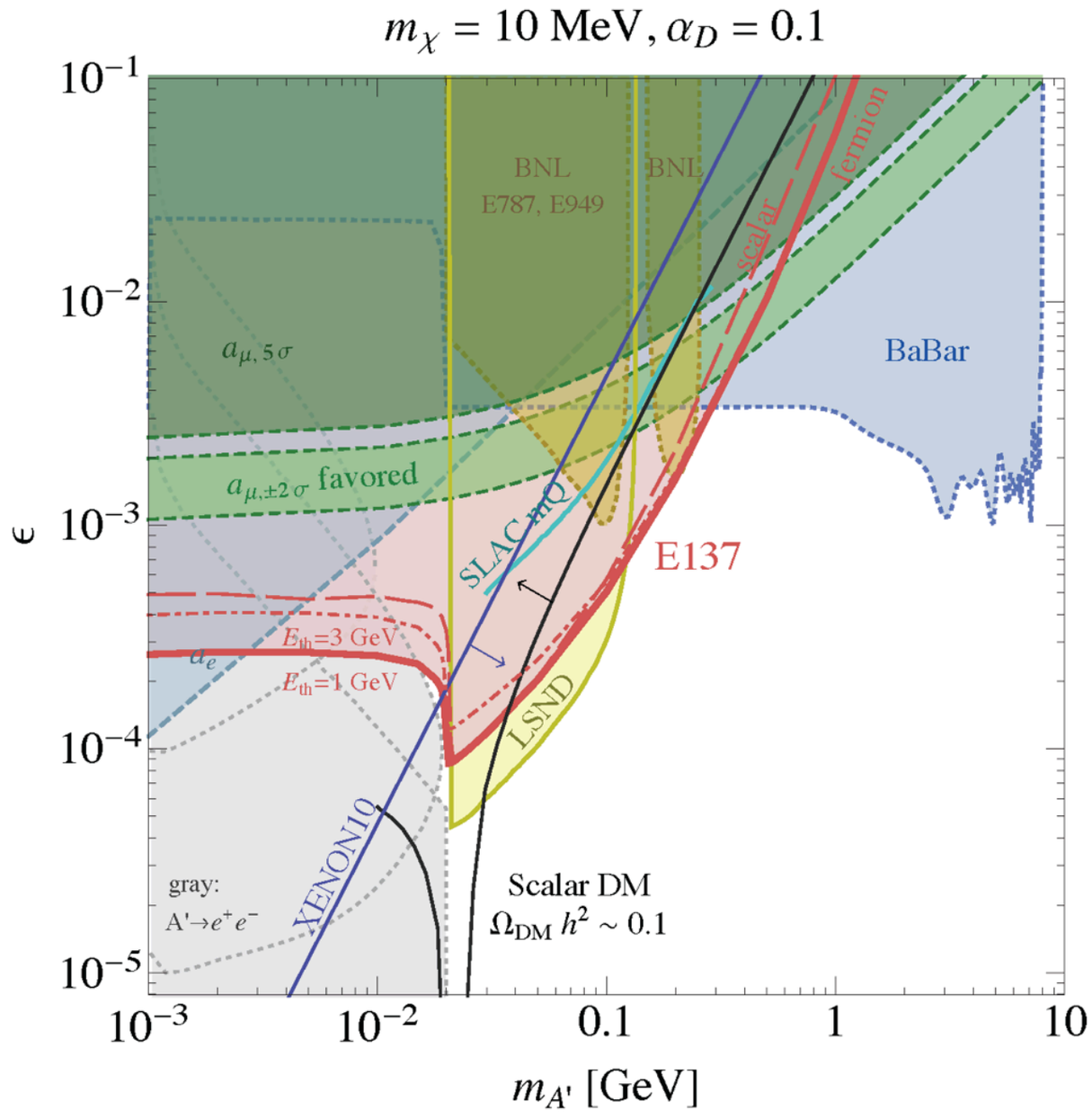
Production



Scattering



Current constraints on vector portal DM



BB, Essig, Surujon

MiniBooNE Search for Light Dark Matter

[Dharmapalan et al. ,(MiniBooNE Collaboration), arXiv:1211.2258]

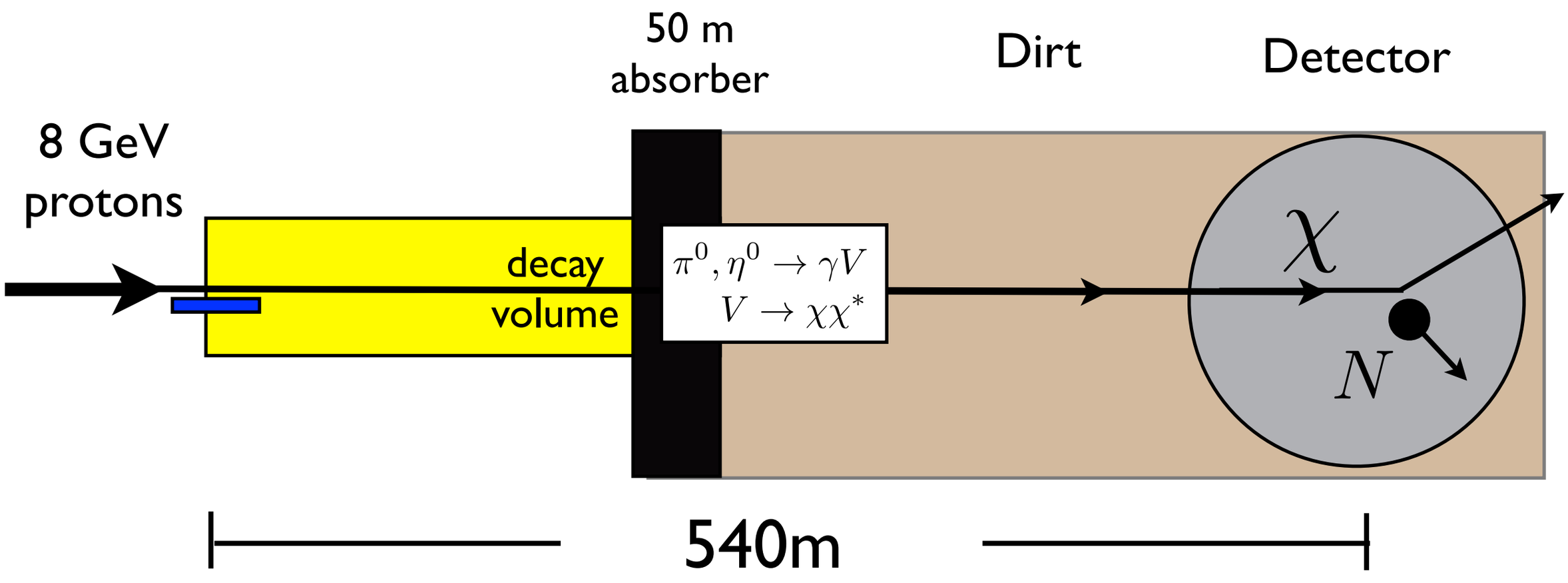
- Basic idea: direct protons onto beam dump to reduce neutrino flux
- Proposal to the FNAL PAC
- Run approved fall 2013; just finished this September
- 2 E 20 POT collected
- Analysis underway - results this year!

Beating down the neutrino background

The signature of dark matter is a neutral current scattering event

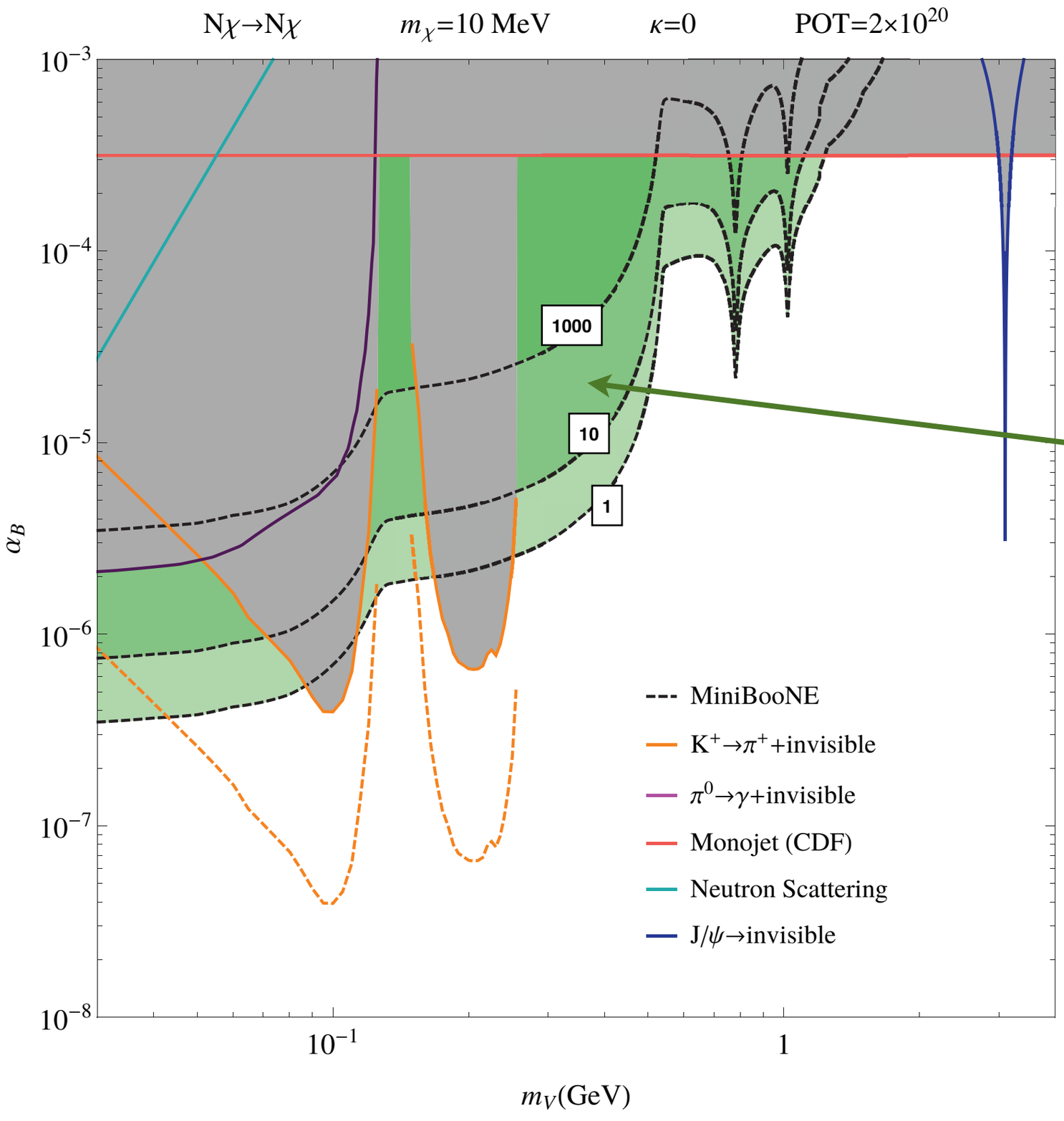
Very similar to neutrino induced neutral current event!

Focus protons onto the beam dump - charged pions absorbed or stopped!



Neutrino background reduced by factor of ~ 50!

MiniBooNE sensitivity to leptophobic DM



MiniBooNE signal

Unique sensitivity over much of the parameter space!

Many promising proposals to probe Sub-GeV Dark Matter

- Direct detection via scattering with electrons Essig, Mardon, Volansky

- Electron Beam fixed target - scattering experiments
  - BDX (Beam Dump eXperiment) Izaguirre, Krnjaic, Schuster, Toro

- Fixed target - missing momentum experiments
  - SPS Proposal P348 http://p-348.web.cern.ch/

    Andreas et al. 1312.3309

(See also
Kahn, Thaler
Izaguirre, Krnjaic, Schuster, Toro)

- Neutrino factories, e.g., DAEdULUS Kahn et al.

Outlook

- Strong empirical hints for new physics (Dark Matter, Neutrino mass, Baryon Asymmetry), but we do not know the scale associated with their dynamics - can be light!

- We have a variety of experimental tools at our disposal to search for such new lights states - high intensity, high precision, and high energy experiments. We must take full advantage of these resources.

- Portals allow a systematic approach to the study of such states.

- We don't know which principle is the right one in guiding us in our search for new physics. We must look everywhere we can - at, above and below the weak scale. Any discovery will be revolutionary!