New physics: light and weakly coupled.
(With focus on muons)

Maxim Pospelov

Perimeter Institute, Waterloo/University of Victoria, Victoria

PSI workshop, 2015

Old papers +

B Batell, N Lange, D McKeen, MP, A Ritz, 1606.08632

Chien-Yi Chen, MP, Yiming Zhong, in preparation

University of Victoria | British Columbia Canada

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

Outline of the talk

1. Introduction I. Portals to light new physics. Generalization: UV physics or IR? Introduction II. UV and IR physics in experiments with muons.
2. Light particles vs g-2 discrepancy: dark photons, invisibly decaying dark photons, scalar particles coupled to muons.
3. New experiments with muons? A muon beam dump search of exotic particles.
4. Conclusions

Opening remarks

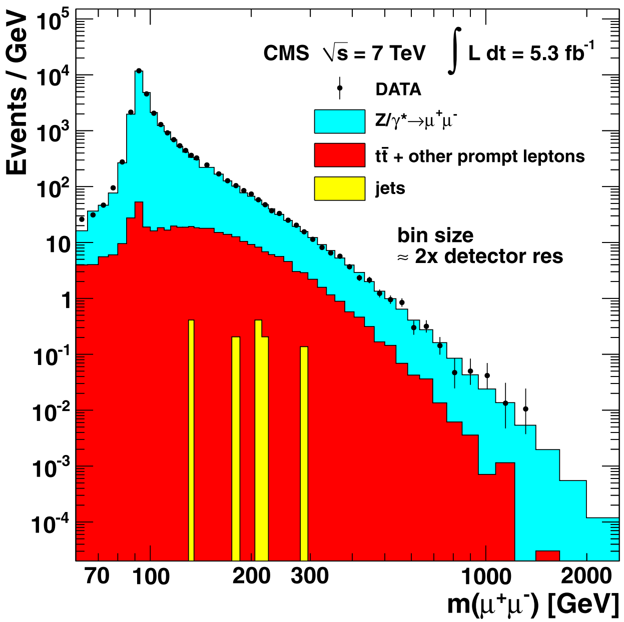
1. *Light weakly coupled new (BSM) physics* is a generic possibility not to be *a priori* discarded. Some (axion!) is well motivated

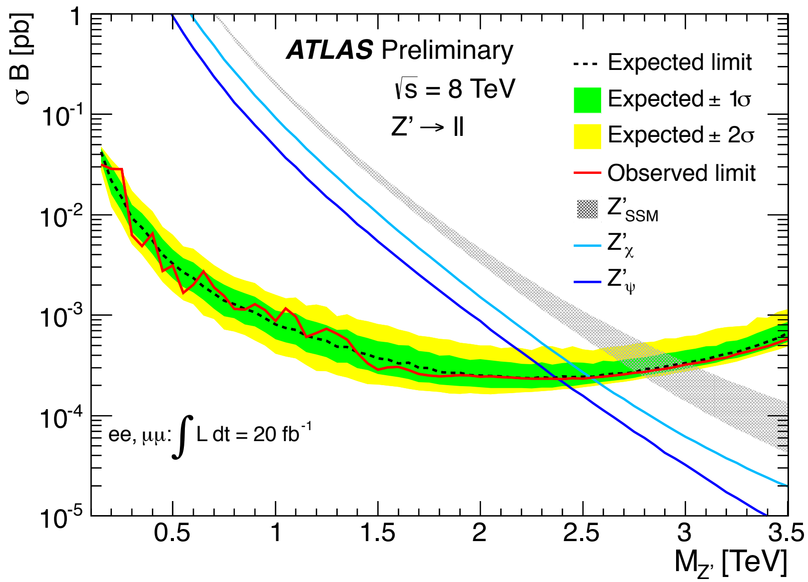
2. If it does not violate any well-tested symmetry, it can mediate a new interactions that are e.g. *stronger* than some SM interactions.

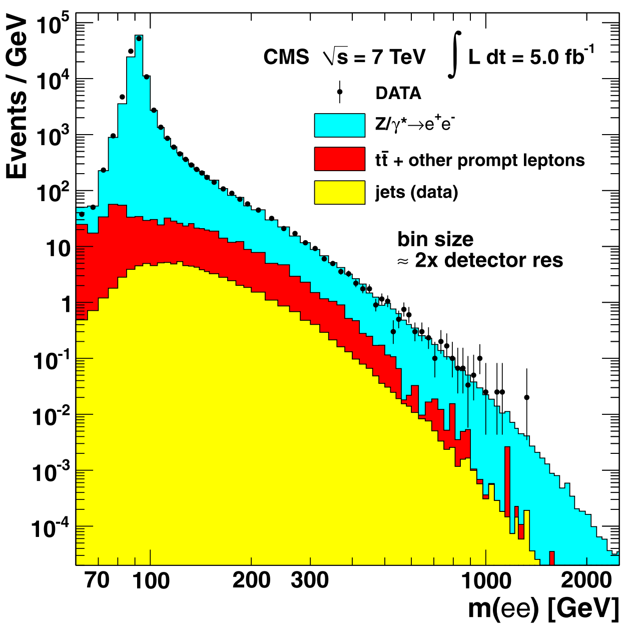
3. Since 2008, there has been *a revival* of the subject (driven initially by some astrophysics "hints"), with old data being repurposed, new searches added, and new experiments being set up. There is still considerable room for *new ideas*. This subject is here to stay.

4. If light NP is proposed to "explain away" some anomalies (g-2, muon H Lamb shift), it is often the case that NP model can be tested faster than the true origin of given discrepancy is found.

No New Physics at high energy thus far (?!)







No hints for any kind of new physics. Strong constraints on SUSY, extra dimensions, technicolor resonances.

Constraints on new *Z'* bosons push the mediator mass into multi-TeV territory.

Constraints on sub-GeV particles are *not* strong, if couplings are weak.

Neutral "portals" to the SM

Let us *classify* possible connections between Dark sector and SM

$H^+H\ (\lambda\, S^2 + A\, S)$ Higgs-singlet scalar interactions (scalar portal)

$B_{\mu\nu} V_{\mu\nu}$ "Kinetic mixing" with additional U(1)' group

(becomes a specific example of $J_\mu^i A_\mu$ extension)

$LH\, N$ neutrino Yukawa coupling, N – RH neutrino

$J_\mu^i A_\mu$ requires gauge invariance and anomaly cancellation

It is very likely that the observed neutrino masses indicate that Nature may have used the *LHN* portal…

Dim>4

$J_\mu^A\ \partial_\mu a\,/f$ axionic portal

……….

$$\mathcal{L}_{\rm mediation} = \sum_{k,l,n}^{k+l=n+4} \frac{\mathcal{O}^{(k)}_{\rm med}\mathcal{O}^{(l)}_{\rm SM}}{\Lambda^n},$$

Precision frontier: UV physics or IR?

Typical approach: we measure an observable (e.g. $\mu \rightarrow e\,\gamma$, EDM, rare meson decays etc), we perform calculation of the same quantity in the SM, take a difference, and whatever is left is interpreted in terms of physics at a TeV, 10 TeV, XXX TeV scales – *all of them being UV scales*.

More correct approach: Assume that New Physics consist of UV pieces, IR pieces or both,

$$\mathcal{L}_{\rm NP} = \mathcal{L}_{\rm UV} + \mathcal{L}_{\rm IR}.$$

$$\mathcal{L}_{\rm UV} = \sum_{d\geq 5} \frac{1}{\Lambda_{\rm UV}^{d-4}} \mathcal{O}_d. \;\; \mathcal{L}_{\rm IR} = \kappa B^{\mu\nu} V_{\mu\nu} - H^\dagger H (AS + \lambda S^2) - Y_N L H N + \mathcal{L}_{\rm hid}$$

If result for NP is consistent with 0, we can set constraints on both. If it is non-zero: then *more work is required in deciding IR or UV*

UV physics or IR: examples of NP that we know

Neutrino oscillations: We know that new phenomenon exists, and if interpreted as neutrino masses and mixing, is it coming from deep UV, via e. .g Weinberg's operator

$$\mathcal{L}_{\rm NP} \propto (HL)(HL)/\Lambda_{\rm UV} \text{ with } \Lambda_{\rm UV} \gg \langle H \rangle$$

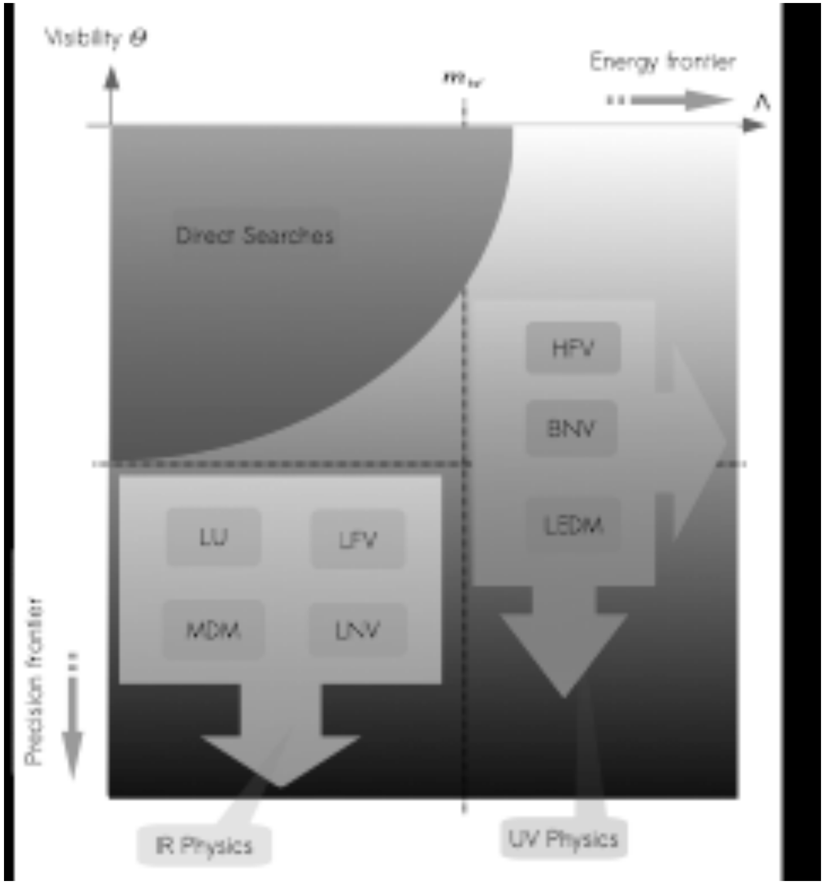
or it is generated by *new IR field*, such as RH component of Dirac neutrinos? *New dedicated experimental efforts are directed in trying to decide between these possibilities.*

Dark matter: 25% of Universe's energy balance is in dark matter: we can set constraints on both. If it is embedded in particle physics, then e.g. neutralinos or axions imply new UV scales.

However, *there are models of DM where NP is completely localized in the IR, and no new scales are necessary*.

New efforts underway both in the UV and IR category.

Mini-analysis



Le Dall, MP, Ritz, 2015

Observable	(A,B) Portals	(C,D) UV-incomplete
LFV	✓	✓
LU	✓	✓
$(g-2)_l$	✓	✓
LNV	✓	✓
LEDMs		✓
HFV		✓
BNV		✓

At current level of experimental accuracy many lepton observables (g-2, LFV, LU) but EDM can be induced by IR physics (e.g. new massive sterile neutrinos below the weak scale).

Quark sector observables would typically require NP at UV scale (except neutron EDM)

Examples with muon experiments

3 categories:

- Capable of probing extremely high energies: LFV experiments, dimuons in B-decays.
- Capable of probing ~ weak scale physics: muon g-2, muon EDM, muon PNC
- Capable of probing GeV-type physics: muon-electron universality via Lamb shift in muonic atoms. Muon capture experiments.

Examples with muon experiments

3 categories:

- Capable of probing extremely high energies: LFV experiments (sizeable effects can come from ~ mutli-TeV physics OR from sub-weak scale sterile neutrinos).

- Capable of probing ~ weak scale physics: muon g-2 (UV or **IR physics**)

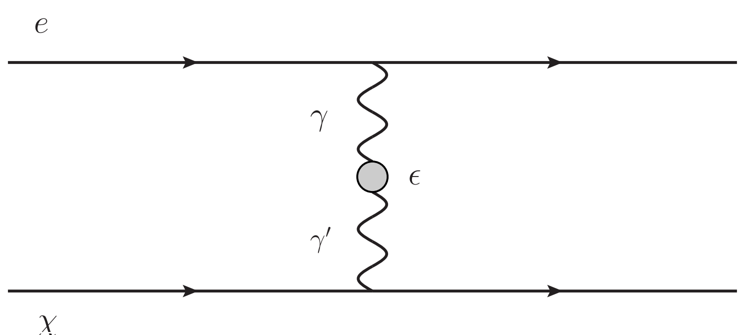
- Capable of probing GeV-type physics: muon-electron universality via Lamb shift in muonic atoms. Muon capture experiments. (If there are deviations that canot be attributed to SM, it can only be IR new physics)

A simple model of dark sector

$$\mathcal{L} = \mathcal{L}_{\psi,A} + \mathcal{L}_{\chi,A'} - \frac{\epsilon}{2} F_{\mu\nu} F'_{\mu\nu} + \frac{1}{2} m^2_{A'} (A'_\mu)^2.$$

$$\mathcal{L}_{\psi,A} = -\frac{1}{4} F^2_{\mu\nu} + \bar{\psi}[\gamma_\mu (i\partial_\mu - eA_\mu) - m_\psi]\psi$$

$$\mathcal{L}_{\chi,A'} = -\frac{1}{4} (F'_{\mu\nu})^2 + \bar{\chi}[\gamma_\mu (i\partial_\mu - g' A'_\mu) - m_\chi]\chi,$$



- "Effective" charge of the "dark sector" particle χ is Q = e × ε (if momentum scale q > m_V). At q < m_V one can say that particle χ has a non-vanishing *EM charge radius*, $r^2_\chi \simeq 6\epsilon m_V^{-2}$.
- Dark photon can "communicate" interaction between SM and dark matter. Very light χ can be possible.

“Non-decoupling” of secluded U(1) Theoretical expectations for masses and mixing

Suppose that the SM particles are not charged under new $U_S(1)$, and communicate with it only via extremely heavy particles of mass scale Λ (however heavy!, e.g. 100000 TeV) charged under the SM $U_Y(1)$ and $U_S(1)$ (B. Holdom, 1986)

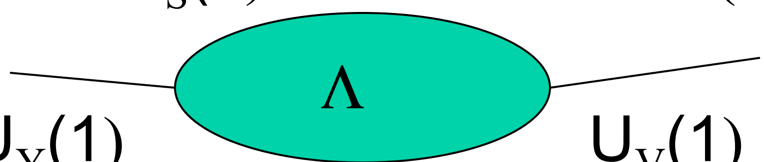


Diagram $U_Y(1)$ $U_V(1)$ does not decouple!

A mixing term is induced, $\kappa\, F^Y_{\mu\nu} F^S_{\mu\nu}$,

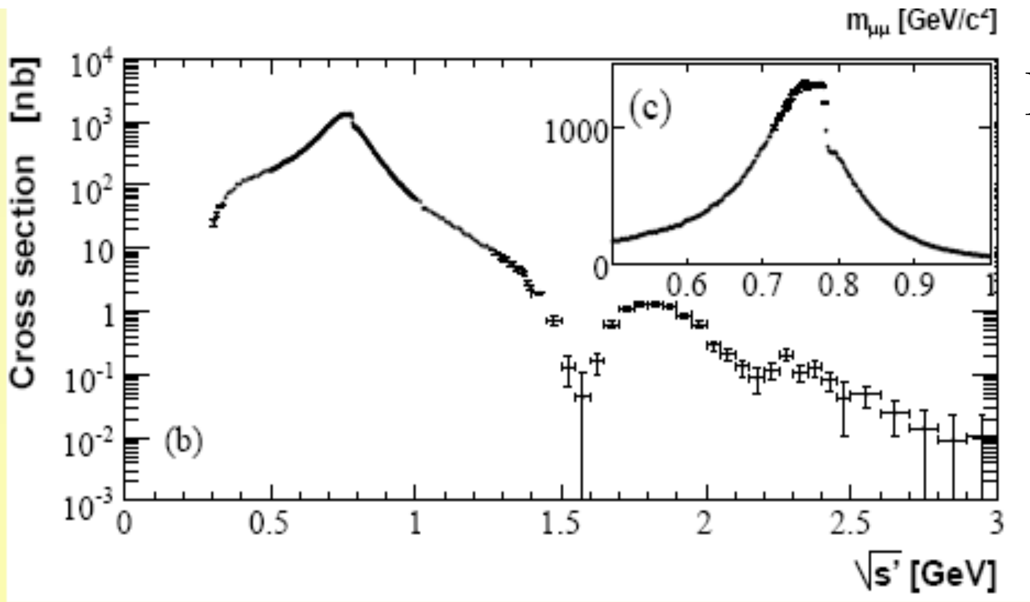
With κ having only the log dependence on mass scale Λ

$\kappa \sim (\alpha\alpha')^{1/2}\, (3\pi)^{-1} \log(\Lambda_{UV}/\Lambda) \sim 10^{-3}$

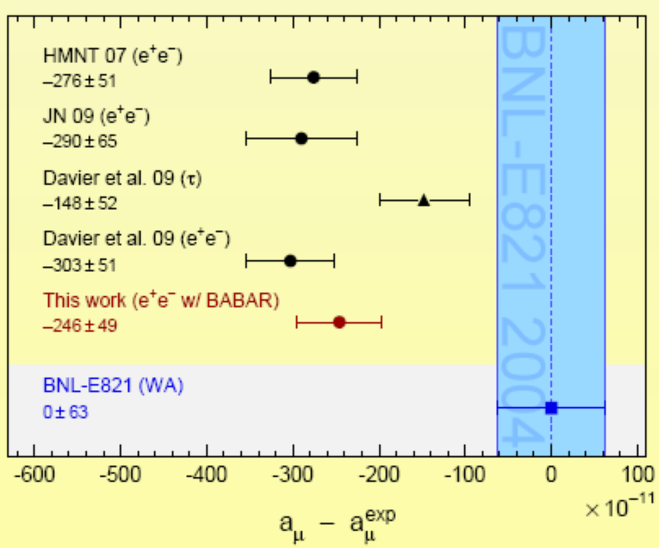
$M_V \sim e'\kappa\, M_{EW}$ (M_Z or TeV) $\sim$ MeV – GeV

This is very “realistic” in terms of experimental sensitivity range of parameters.

g-2 of muon



More than 3 sigma discrepancy for most of the analyses. Possibly a sign of new physics, but some complicated strong interaction dynamics could still be at play.



✱ Davier et al. arXiv:0906-5443

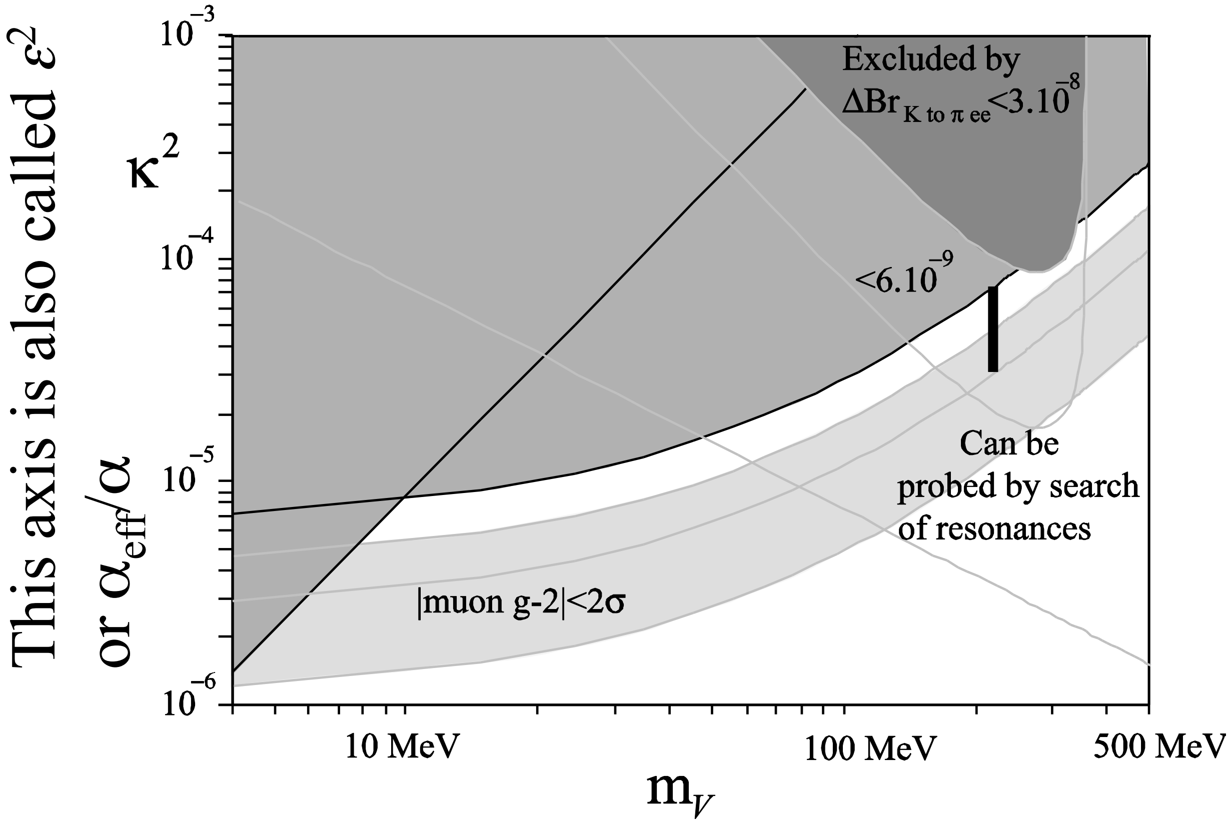
Supersymmetric models with large-ish *tanβ*; light-ish sleptons, and right sign of μ parameter can account for the discrepancy.

Sub-GeV scale vectors/scalars can also be at play.

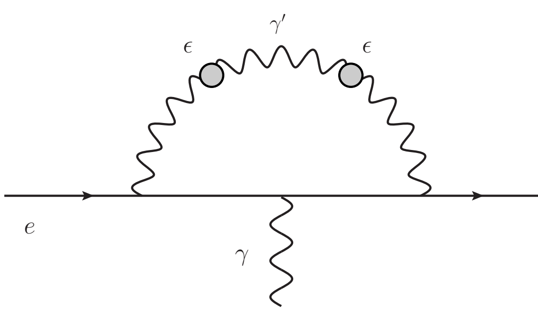
g-2 signature of light particles

If g-2 discrepancy taken seriously, a new vector force can account for deficit. (Krasnikov, Gninenko; Fayet; Pospelov)

E.g. mixing of order few 0.001 and mass $m_V \sim m_\mu$

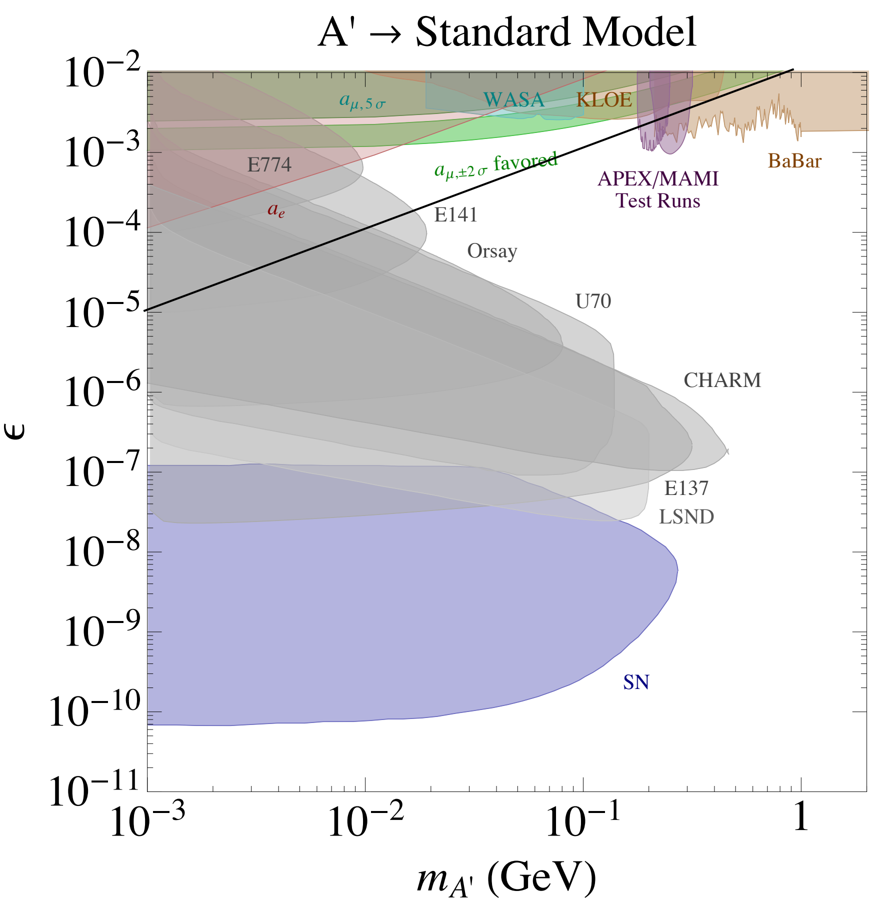


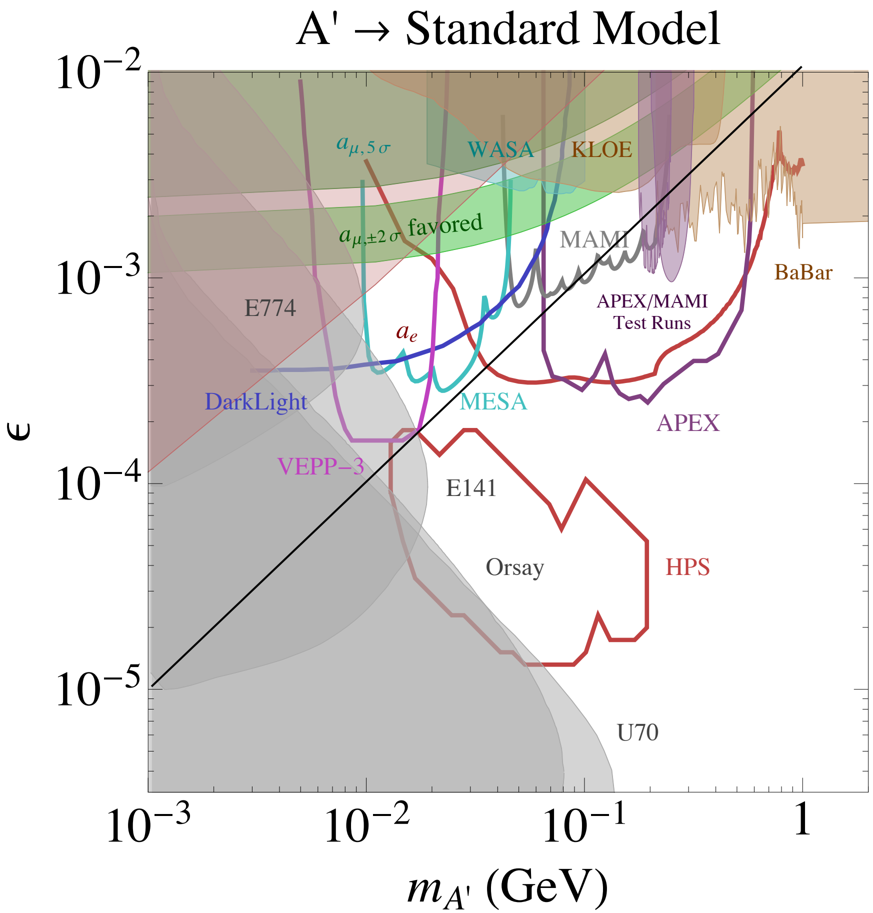
MP, 2008



Since 2008 a lot more of parameter space got constrained

ε-m_V parameter space, Snowmass study, 2013





Dark photon models with mass under 1 GeV, and mixing angles ~ 10^{-3} represent a "window of opportunity" for the high-intensity experiments, and soon the g - 2 ROI will be completely covered. *Gradually, all parameter space in the "SM corner" gets probed/excluded.*

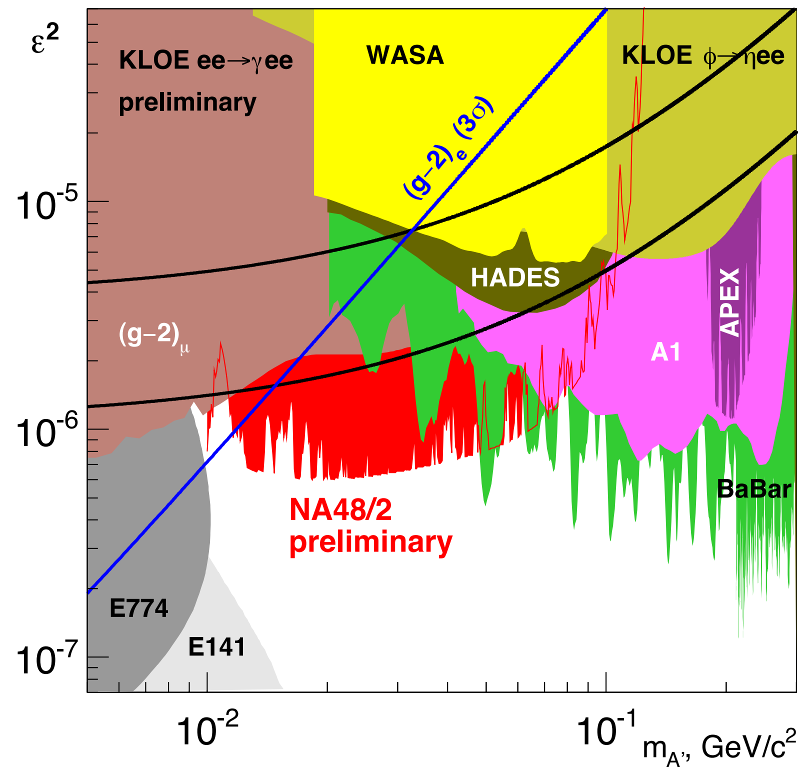
Latest results: A1, Babar, NA48

Signature: "bump" at invariant mass of e^+e^- pairs = $m_{A'}$

Babar: $e^+e^- \rightarrow \gamma V \rightarrow \gamma l^+l^-$

A1(+ APEX): $Z e^- \rightarrow Z e^- V \rightarrow Z e^- e^+e^-$

NA48: $\pi^0 \rightarrow \gamma V \rightarrow \gamma e^+e^-$
Latest results by NA48 exclude the remainder of parameter space relevant for g-2 discrepancy.



Only *less minimal* options for muon g-2 explanation remain:
A. $L_\mu - L_\tau$, B. Dark photons *decaying* to dark state (light dark matter), C. dark scalar

Muon pair-production by neutrinos

VOLUME 66, NUMBER 24 PHYSICAL REVIEW LETTERS 17 JUNE 1991

Neutrino Tridents and *W*-*Z* Interference

S. R. Mishra,[a] S. A. Rabinowitz, C. Arroyo, K. T. Bachmann,[b] R. E. Blair,[c] C. Foudas,[d] B. J. King,

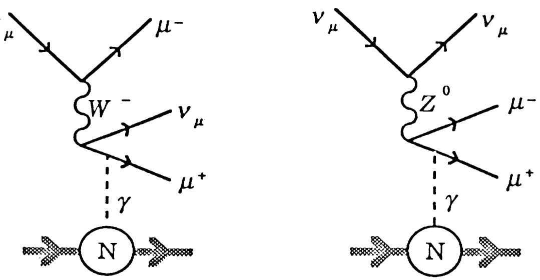


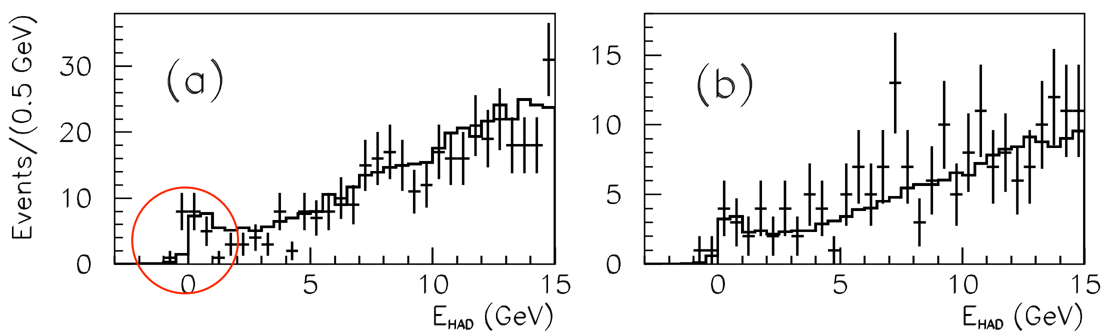
FIG. 1. Feynman diagram showing the neutrino trident production in ν_μ-A scattering via the W and the Z channels.

$$\sigma_{\nu N}(\mathrm{CC}) = (0.680 \pm 0.015) E_\nu \times 10^{-38}\ \mathrm{cm}^2/\mathrm{GeV}\ ,$$

$$\sigma(\nu\ \mathrm{trident}) = (4.7 \pm 1.6) E_\nu \times 10^{-42}\ \frac{\mathrm{cm}^2}{\mathrm{Fe\ nucleus}}$$

$$\mathrm{at}\ \langle E_\nu \rangle = 160\ \mathrm{GeV}\ .$$

- NuTeV results:



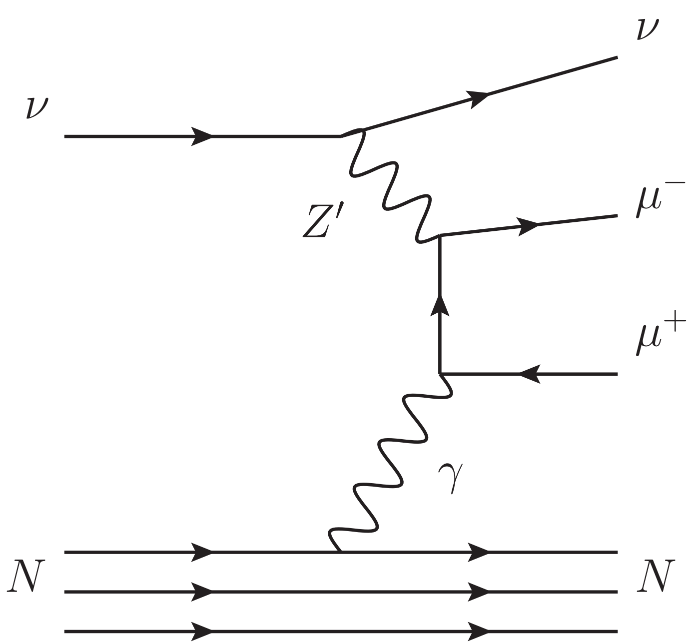
Trident production was seeing with O(20) events, and is fully consistent with the SM destructive W-Z interference.

Additional contribution from Z' of L_μ - L_τ

Experimental results

$$\sigma_{\mathrm{CHARM-II}}/\sigma_{\mathrm{SM}} = 1.58 \pm 0.57\ ,$$
$$\sigma_{\mathrm{CCFR}}/\sigma_{\mathrm{SM}} = 0.82 \pm 0.28\ ,$$
$$\sigma_{\mathrm{NuTeV}}/\sigma_{\mathrm{SM}} = 0.67 \pm 0.27\ .$$

Hypothetical Z' (any Z' coupled to L_μ) contributes constructively to cross section.

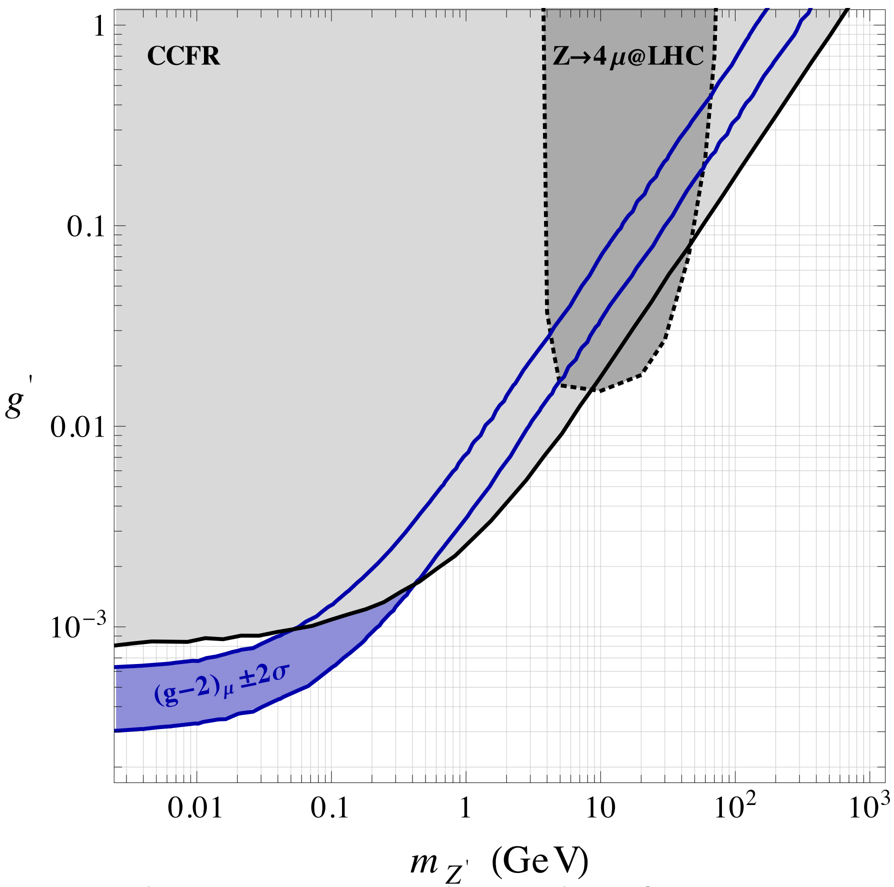


In the heavy Z' limit the effect simply renormalizes SM answer:

$$\frac{\sigma}{\sigma_{\mathrm{SM}}} \simeq \frac{1 + \left(1 + 4s_W^2 + \overset{\approx 4}{2v^2/v_\phi^2}\right)^2}{1 + \left(1 + 4s_W^2\right)^2}$$

~8-fold enhancement of cross section

Full result on $M_{Z'}$ - g' parameter space



Muon pair production process excludes solutions to muon g-2 discrepancy via gauged muon number in the whole range of

$M_{Z'} > 400$ MeV

In the "contact" regime of heavy Z'>5 GeV, the best resolution to g-2 overpredicts muon trident cross section by a factor of ~ 8.

Can it be improved in the future at DUNE (O(50) events /yr) ???

Altmannshofer, Gori, MP, Yavin, PRL, 2014

(There are also variations of the simplest model Altmannshofer et al., C.Y. Chen et al, that can correct g-2 in a wider range of masses)

Dark photons decaying invisibly or into DM

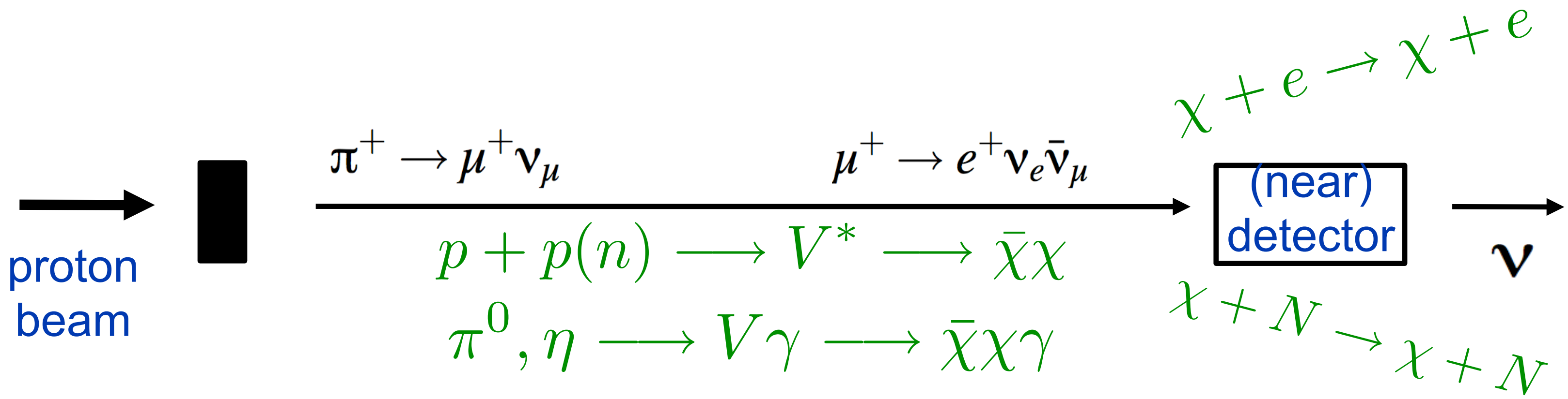
May be dark photon (or dark photon-type particles) decay invisibly, e.g. into the light dark matter, and thus escape detection.

- Look for missing energy in the scattering or decay (NA62 in kaon decays, NA64 in electron scattering on target)

- Look for production and subsequent scattering of light dark matter (Miniboone)

Fixed target probes - Neutrino Beams

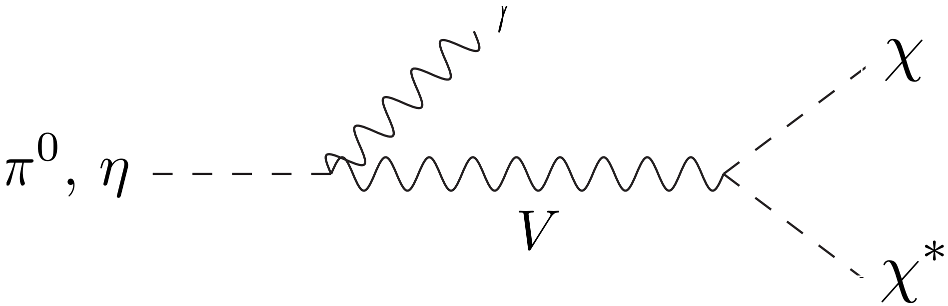
Proposed in Batell, MP, Ritz, 2009. Strongest constraints on MeV DM

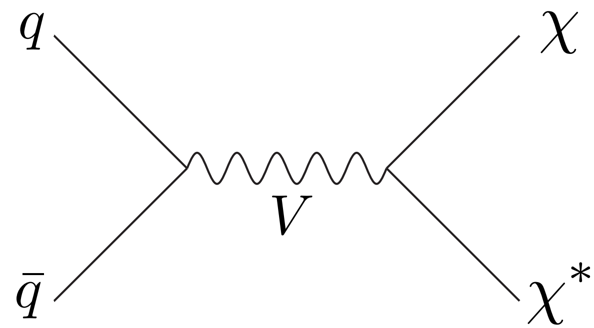


We can use the neutrino (near) detector as a dark matter detector, looking for recoil, but now from a relativistic beam. E.g.

T2K	**MINOS**	**MiniBooNE**
30 GeV protons	120 GeV protons	8.9 GeV protons
(➠ ~5x10^{21} POT)	10^{21} POT	10^{21} POT
280m to on- and off-axis detectors	1km to (~27ton) segmented detector	540m to (~650ton) mineral oil detector

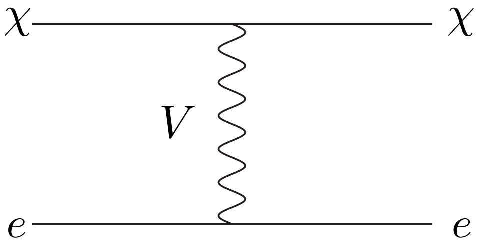
Light DM - trying to force the issue



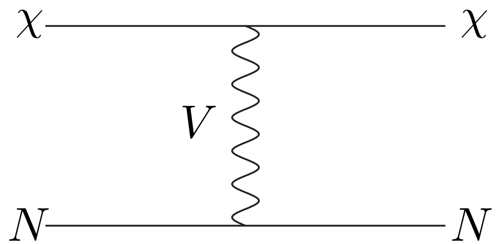


In the detector:

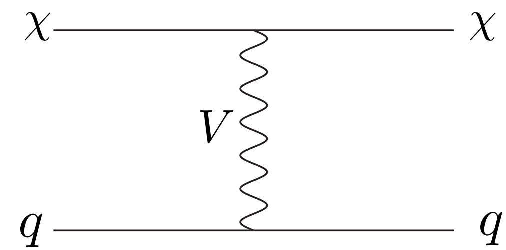
Elastic scattering on electrons



Elastic scattering on nucleons

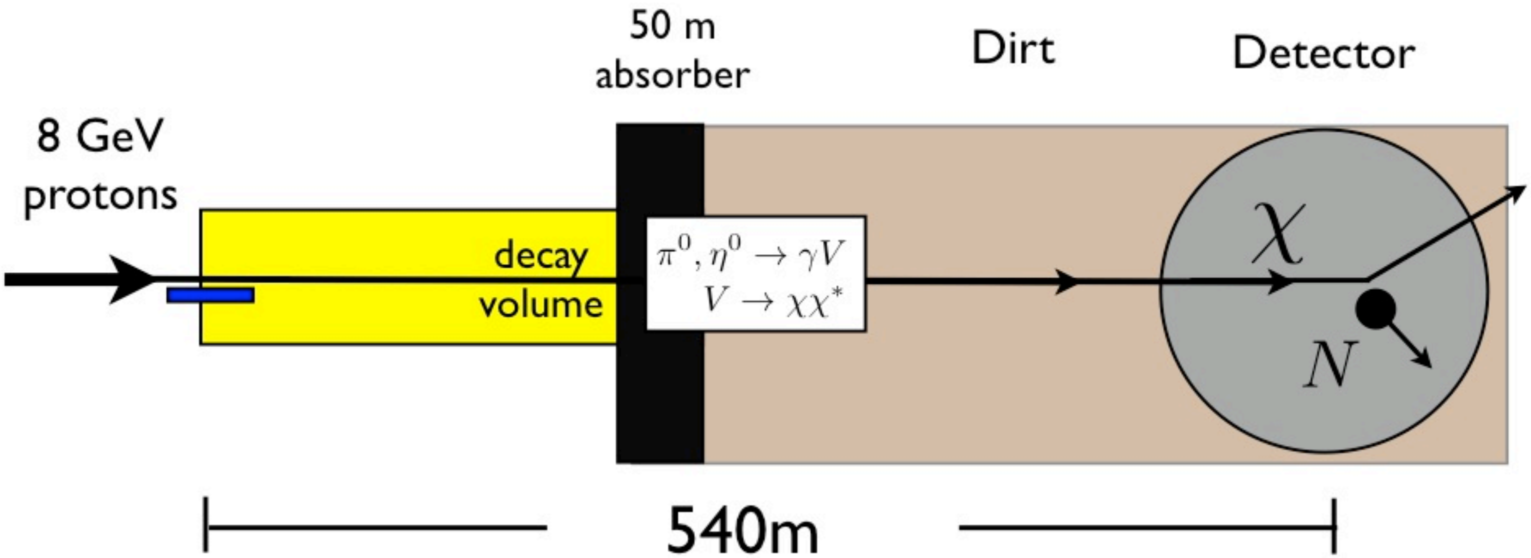


Deep inelastic scattering



Same force that is responsible for depletion of χ to acceptable levels in the early Universe will be responsible for it production at the collision point and subsequent scattering in the detector.

MiniBooNE search for light DM



MiniBoone has completed a long run in the beam dump mode, as suggested in [arXiv:1211.2258]

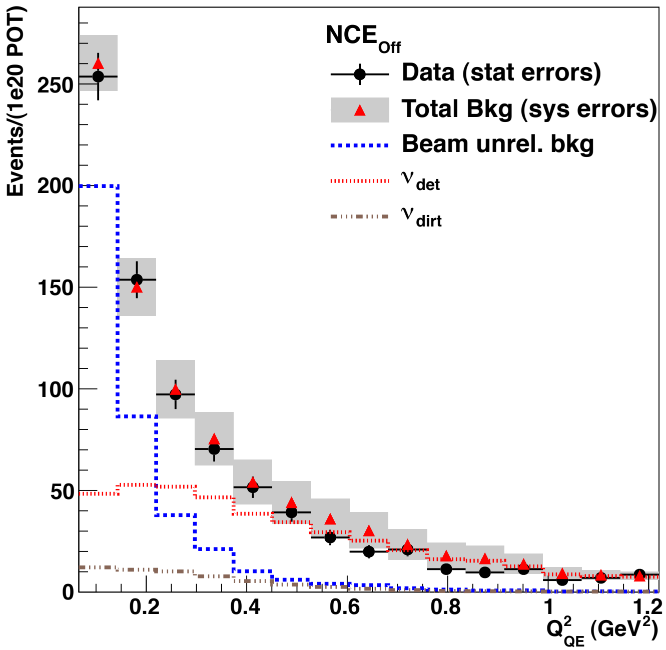
By-passing Be target is crucial for reducing the neutrino background (Richard van de Water et al. …) . Currently, suppression of ν flux ~50.

Timing is used (10 MeV dark matter propagates slower than neutrinos) to further reduce backgrounds. First results – this year (2016)

Fermilab W&C talk by R.T. Thornton last month.

On-going and future projects

From the W & C talk by Thornton

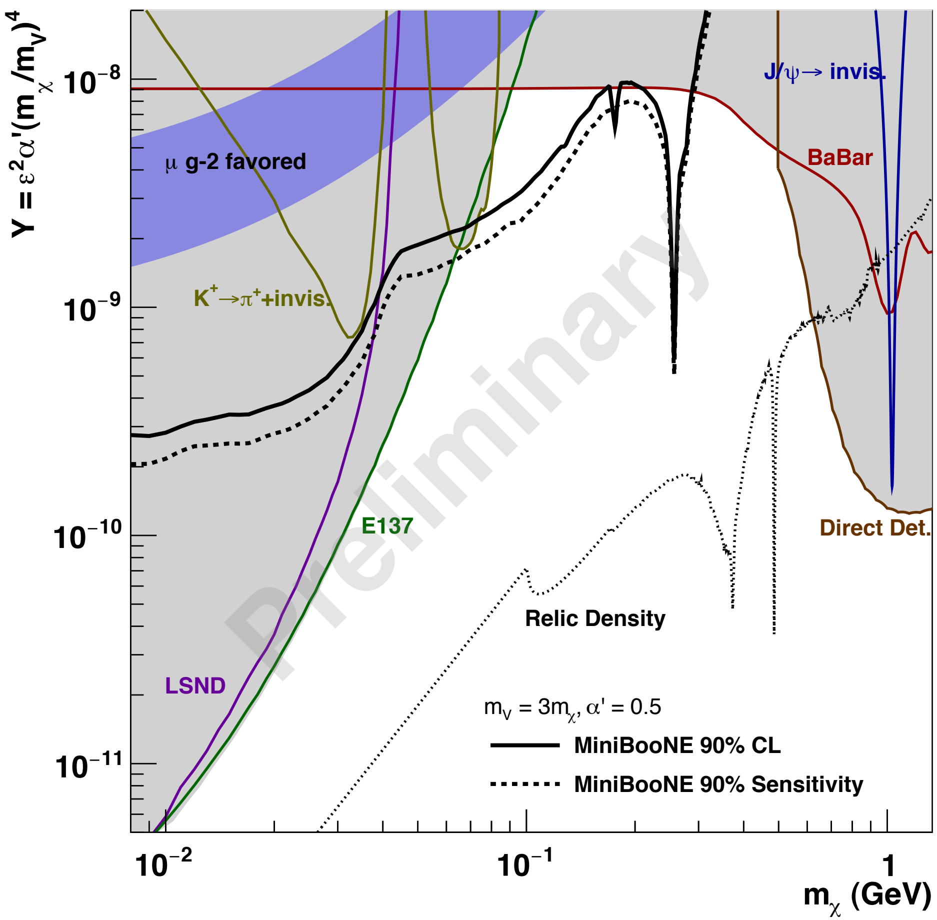


	#events	uncertainty
BUB	697	
ν_{det} bkg	775	
ν_{dirt} bkg	107	
Total Bkg	1579	14.3% (pred. sys.)
Data	1465	2.6% (stat.)

The off-target run of MiniBoone is a success (despite the absence of DM signal!):

- Neutrino background from the beam is brought down to be comparable from cosmics
- Data are well described by MC

New parts of the parameter space get excluded



Improves over LSND, SLAC experiments, and Kaon decays in the range of the mediator mass from ~ 100 to few 100 MeV. (My collaborators, B Batell and P deNiverville joined the collaboration to help out!)

Missing energy/momentum searches

NA64 has recent results (great sensitivity after 3×10^9 e on target).
Plot from Banerjee et al, 1610.02988

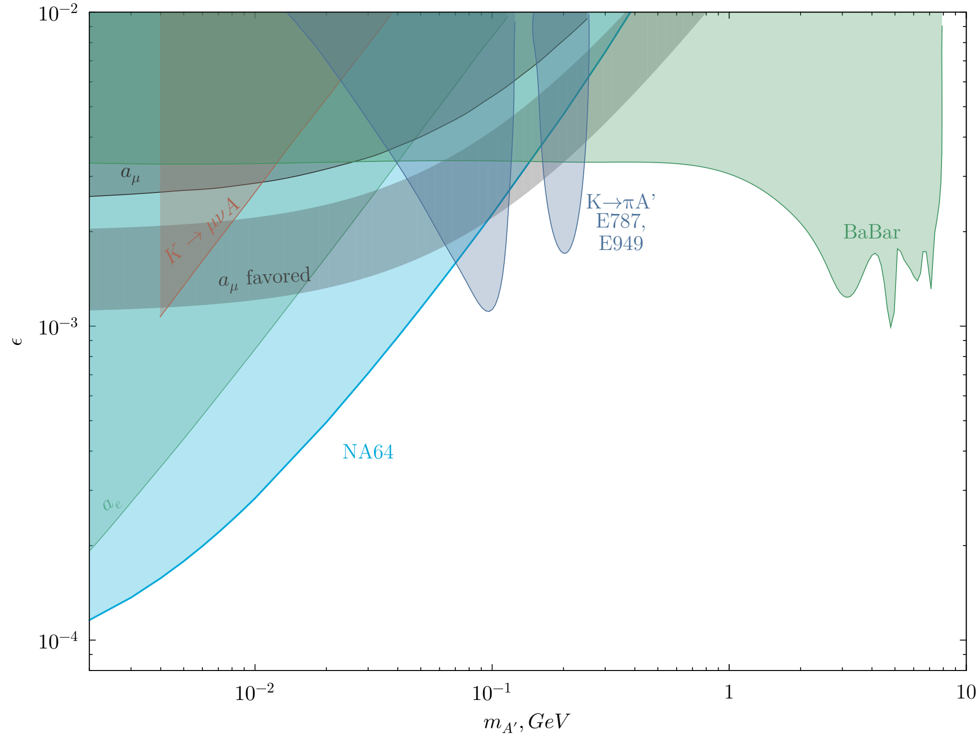


FIG. 3: The NA64 90 % C.L. exclusion region in the $(m_{A'}, \epsilon)$ plane. Constraints from the BaBar [48, 55], and E787+ E949 experiments [47, 56], as well as muon α_μ favored area are also shown. Here, $\alpha_\mu = \frac{g_\mu - 2}{2}$. For more limits obtained from indirect searches and planned measurements see e.g. Refs. [5].

On-going and future projects

Fixed Target/beam dump experiments sensitive to

- Dark Photons: HPS, DarkLight, APEX, Mainz, SHiP…
- Light dark matter production + scattering: MiniBoNE, BDX, SHiP…
- Right-handed neutrinos: SHiP
- Missing energy via DM production: NA62 ($K \rightarrow \pi\nu\nu$ mode), positron beam dumps…
- Extra Z' in neutrino scattering: DUNE near detector (?)

Light scalar particles and g-2

$$\mathcal{L}_{\rm eff} = \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m_S^2 S^2 + \sum_{l=e,\mu,\tau} g_\ell S\bar{\ell}\ell,$$

This is a *simplified* model that does not have a full SM gauge invariance. It needs UV completion. The interaction term must be somehow an effective operator ~ $\mathcal{O}_5 = \frac{1}{\Lambda}(\bar{L}E)HS,$

Two UV completions exist:

Chen, Marciano, Davoudiasl, 1511.04715, via vector-like fermions

Lange et al, 1606.04943, via lepton-specific two-Higgs doublet model.

[These are not particularly elegant models, but they are self-consistent. I doubt the same can be said about models with a strong pseudoscalar * (F Fdual) coupling, cf. M Passera talk]

Light scalar particles and g-2

$$\mathcal{L}_{\rm eff} = \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m_S^2 S^2 + \sum_{l=e,\mu,\tau} g_\ell S\bar{\ell}\ell,$$

It is well-known (Kinoshita, Marciano, the 80s) that a loop of a light scalar particle with Higgs-size couplings (g ~ m_μ /v) induces positive correction to g-2,

$$\Delta a_\mu = \frac{g_\mu^2}{8\pi^2}\int_0^1 dz \frac{(1-z)^2(1+z)}{(1-z)^2 + z(m_S/m_\mu)^2}.$$

that is in the "right range" , + 3×10^{-9}.

One *cannot* use a light scalar admixed to the SM Higgs via *S* (H^+H) as this model is far too well constrained via flavour physics.

UV completion via leptonic 2HDM + singlet scalar

Consider 2HDM where one of the Higgses (Φ_1) will mostly couple to leptons, and also mixes with a singlet that is "light" relative to EW scale.

$$V = V_{\rm 2HDM} + V_S + V_{\rm portal}$$

$$V_{\rm 2HDM} = m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - m_{12}^2 \left(\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1\right) + \frac{\lambda_1}{2}\left(\Phi_1^\dagger \Phi_1\right)^2 + \frac{\lambda_2}{2}\left(\Phi_2^\dagger \Phi_2\right)^2$$

$$+ \lambda_3 \left(\Phi_1^\dagger \Phi_1\right)\left(\Phi_2^\dagger \Phi_2\right) + \lambda_4 \left(\Phi_1^\dagger \Phi_2\right)\left(\Phi_2^\dagger \Phi_1\right) + \frac{\lambda_5}{2}\left[\left(\Phi_1^\dagger \Phi_2\right)^2 + \left(\Phi_2^\dagger \Phi_2\right)^2\right]$$

$$V_S = BS + \frac{1}{2} m_0^2 S^2 + \frac{A_S}{2} S^3 + \frac{\lambda_S}{4} S^4$$

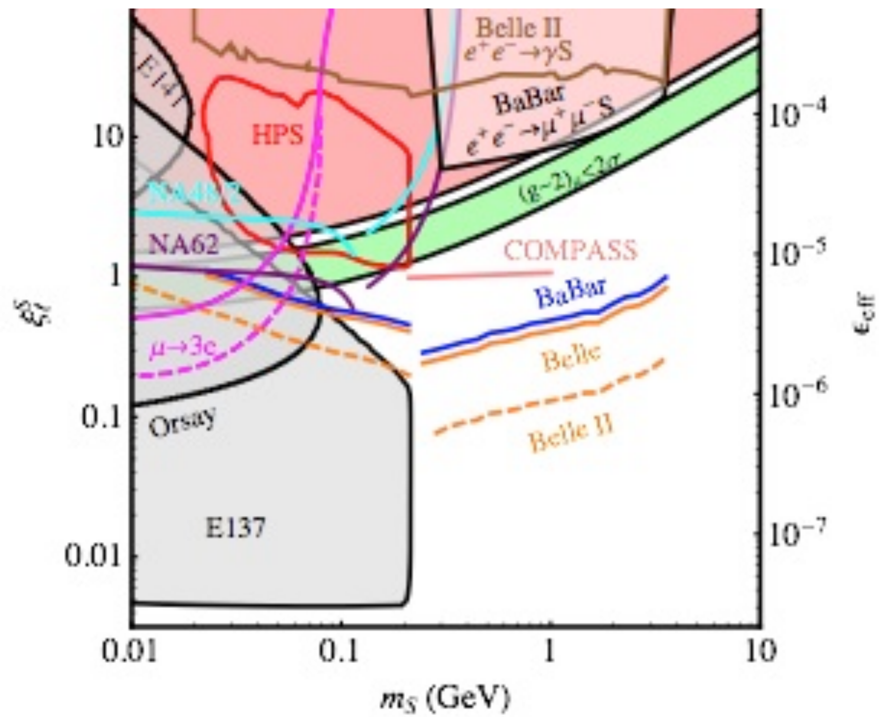
$$V_{\rm portal} = S\left[A_{11}\Phi_1^\dagger \Phi_1 + A_{22}\Phi_2^\dagger \Phi_2 + A_{12}\left(\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1\right)\right]$$

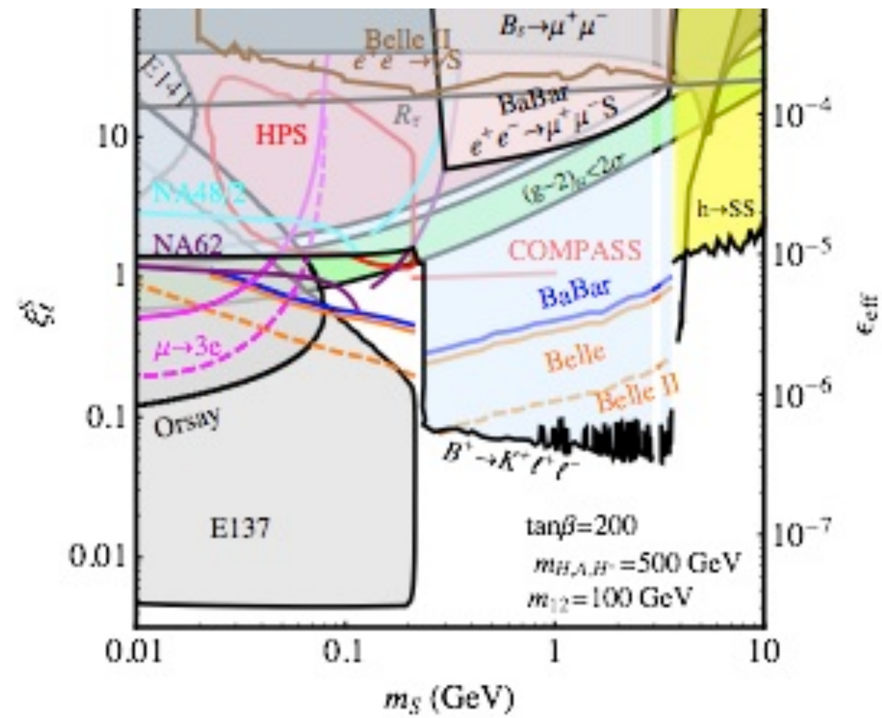
Calling the the lightest scalar particle *S*, one takes a large tan beta regime, and considers an effective low-energy Lagrangian

$$\mathcal{L}_{\rm eff} = \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2} m_S^2 S^2 + \sum_{l=e,\mu,\tau} g_\ell S \bar{\ell} \ell, \qquad g_\ell = \xi_\ell^S m_\ell / v$$

where it is important that 1. S can be light, 2. couples mostly to leptons, proportionally to their masses. This leads to an effective "reweighting" of the traditional e-mV parameter space for all effect involving leptons.

Compillation of constraints





$$\kappa_{\rm eff} \equiv m_e \xi_{\ell\ell}/ev$$

Batell, Lange, McKeen, Pospelov, Ritz, 1606.04943

B-factory signal from the associated ττ + Scalar → ττμμ production is a new suggested search

Simplified model are far less constrained than the full UV-complete one

What else can be done with muons ?

- Precision g-2
- Precision EDM (currently a very weak bound)
- LFV, including $\mu \rightarrow e\, \gamma$, and $\mu \rightarrow 3e$.
- Parity tests in NC (will be discussed at a muonic atom workshop tomorrow)
- Search for ligth particles in muon capture and decay
- Muon beam dump experiments
- ….

A new muon beam dump to look for light New Physics

Advantages:

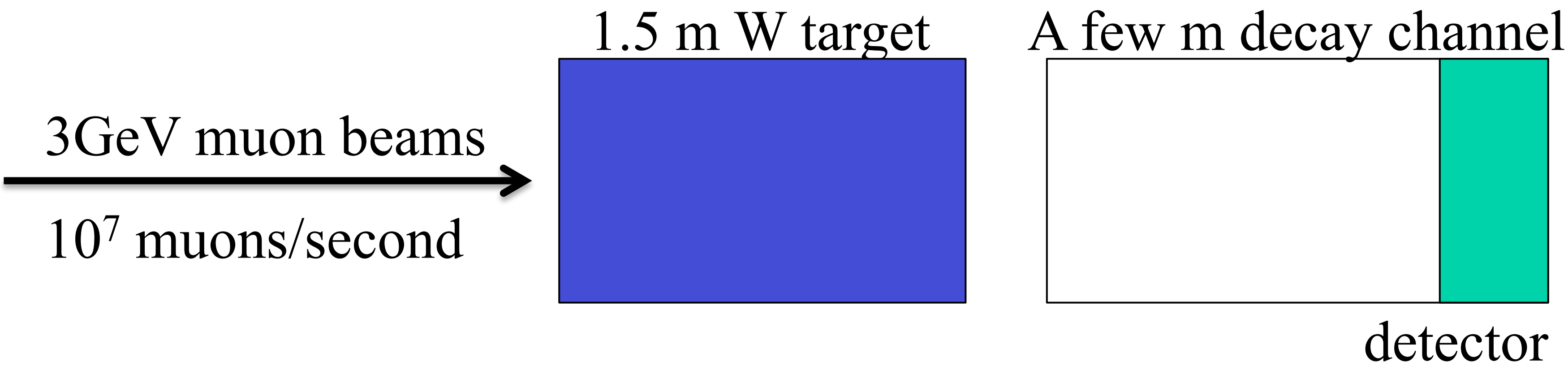
- Much of light NP was motivated by muon g-2 – makes sense to use muons to check on it.
- Haven't been done in a dedicated experiment – easy to break into new territory in some models.
- Fermilab wants to do muon physics (which hopefully will go beyond 2 existing experiments) + beams are well suited for a beam dump (good energy range, high intensity, pulsed).

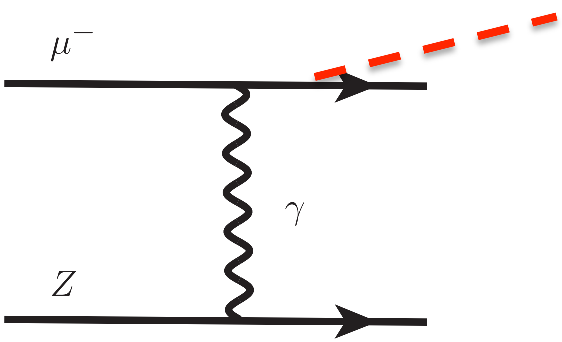
Disadvantages:

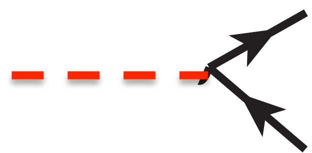
- Far smaller POTs than in *e* or *p* beam dumps. Need models with $g_\mu >> g_e$, g_q. (E.g. not good for "dark photons")
- …

Muon beam dump with a few GeV muon beam

With Chien-Yi Chen and Yiming Zhong.







Electrons or photons from delayed decays

Back to the model with scalars coupled to muons !

Muon beam dump with a few GeV muon beam

We study the same "simplified model"

$$\mathcal{L}_{eff} = \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m^2 S^2 - \sum_{\ell=e,\mu,\tau} g_\ell S\bar{\ell}\ell.$$

and consider the case of two coupling choices with $m_S < 210$ MeV

Case A: Mass proportionality, $g_\ell \sim m_\ell$. $S \rightarrow \bar{e}e$

Case B: "Only muons", $g_{e,\tau} = 0$, $g_\mu \neq 0$. $S \rightarrow \gamma\gamma$

Typical lifetimes for $E_S = 3$ GeV :

$$L_S = 25 \text{ cm} \times \left(\frac{5\times 10^{-4}}{g_\mu}\right)^2 \times \left(\frac{100 \text{ MeV}}{m_S}\right)^2, \quad \text{Case A},$$

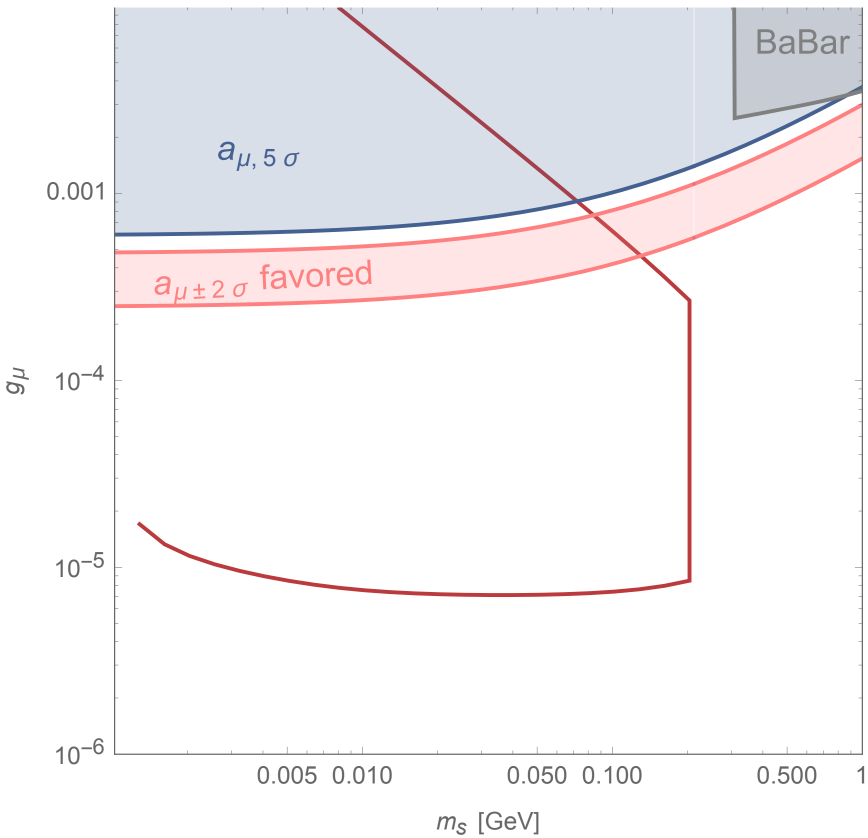
$$L_S = 20 \text{ m} \times \left(\frac{5\times 10^{-4}}{g_\mu}\right)^2 \times \left(\frac{100 \text{ MeV}}{m_S}\right)^2, \quad \text{Case B}.$$

Will g-2 motivated region be covered?

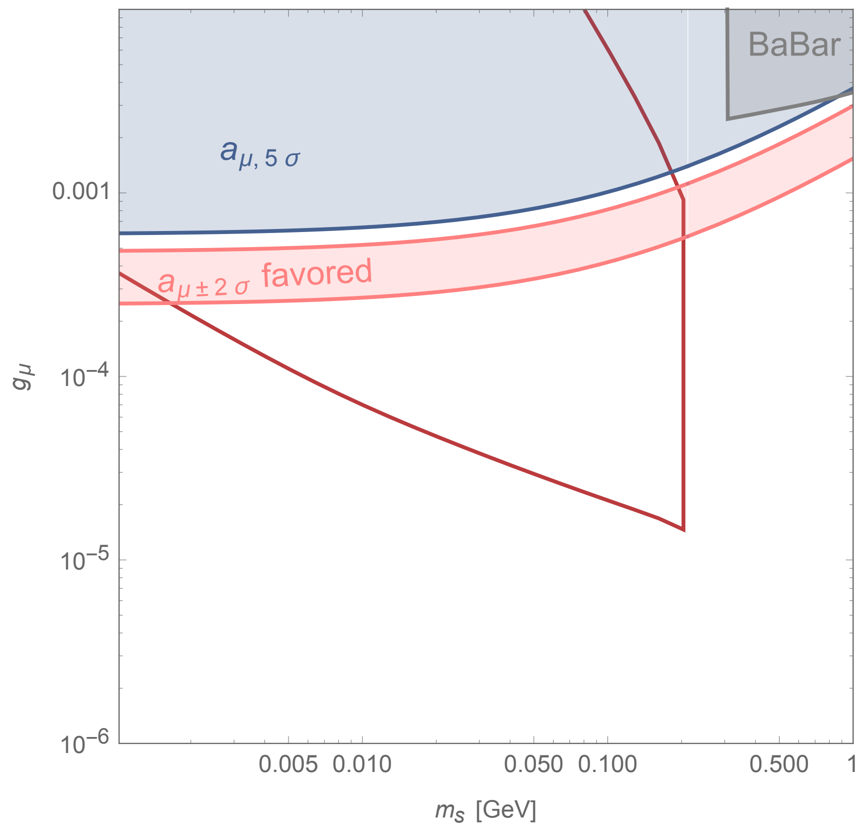
Muon beam dump with a few GeV muon beam

Muon momentum = 3 GeV, 2.5 m W target, 3 m decay channel,
3×10^{14} POT, no background.

Case A: decay to electrons



Case B: decay to photons



Excellent reach in parameter space. Almost complete coverage.

Conclusions

1. Light New Physics (not-so-large masses, tiny couplings) is a generic possibility. Some models (dark photon, scalar coupled Higgs portal) are quite natural, and can be searched for in fixed target experiments.
2. Concerted effort in "dark photon" case rules out minimal model as a cause of g-2 discrepancy. Other possibilities remain.
3. New results from MiniBoone and NA64 further constrain models with invisible decays of dark photons.
4. Scalar models coupled to muons, and correcting g-2 discrepancy, are limited but not excluded (due to smaller coupling to electrons). In the mass range $m_{scalar} < 2\ m_\mu$ there is a possibility to search for new light states via muon beam dump experiments. Fermilab beams can give very good sensitivity to this type of light new physics.

More discrepancies discovered using muons !

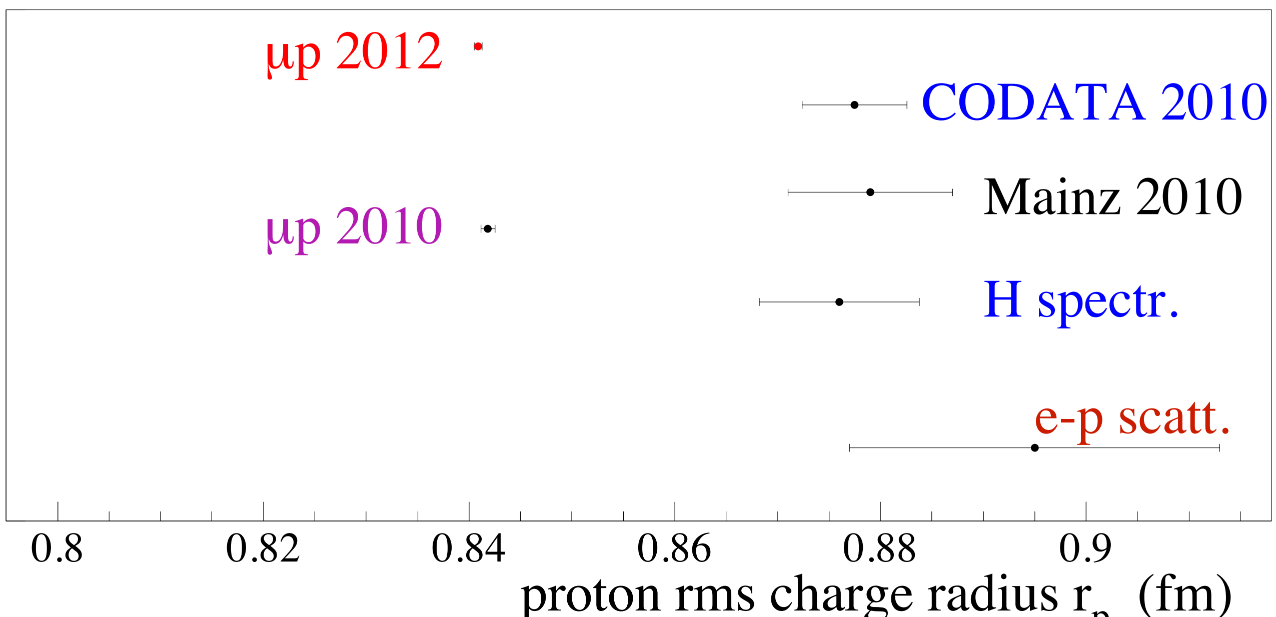
$\nu(2S_{1/2}^{F=1} \to 2P_{3/2}^{F=2})$ = 49881.88(76) GHz R. Pohl *et al.*, Nature 466, 213 (2010)

49881.35(64) GHz preliminary

$\nu(2S_{1/2}^{F=0} \to 2P_{3/2}^{F=1})$ = 54611.16(1.04) GHz preliminary

Proton charge radius: r_p = 0.84089 (26)$_\mathrm{exp}$ (29)$_\mathrm{th}$ = 0.84089 (39) fm (prel.)

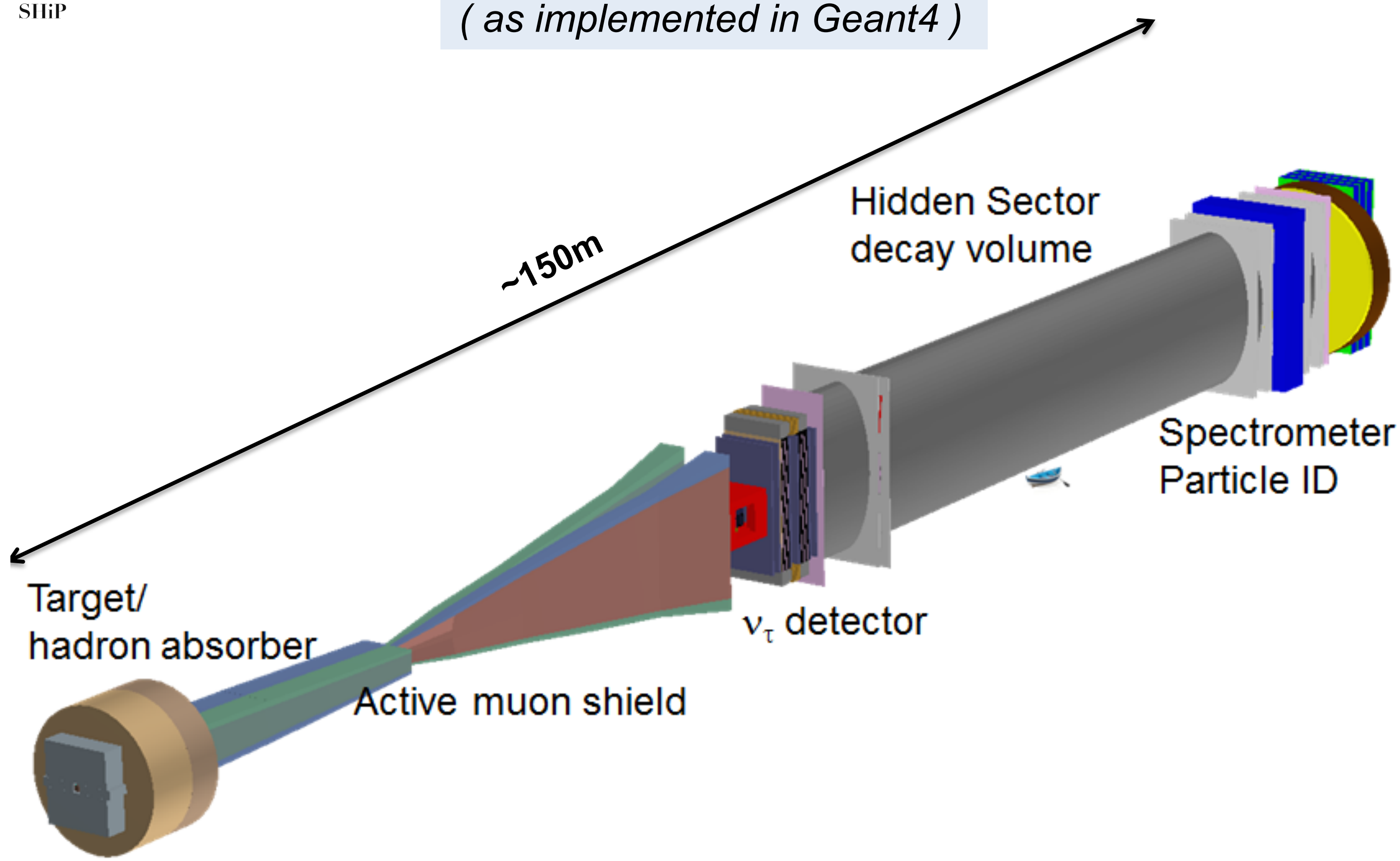
μp theory: A. Antogini *et al.*, arXiv :1208.2637 (atom-ph)



If new physics is responsible for that, it cannot be weak scale, only very light, as r_p will require ~ 10^4 G_F effects…

Future big project: SHiP project at CERN

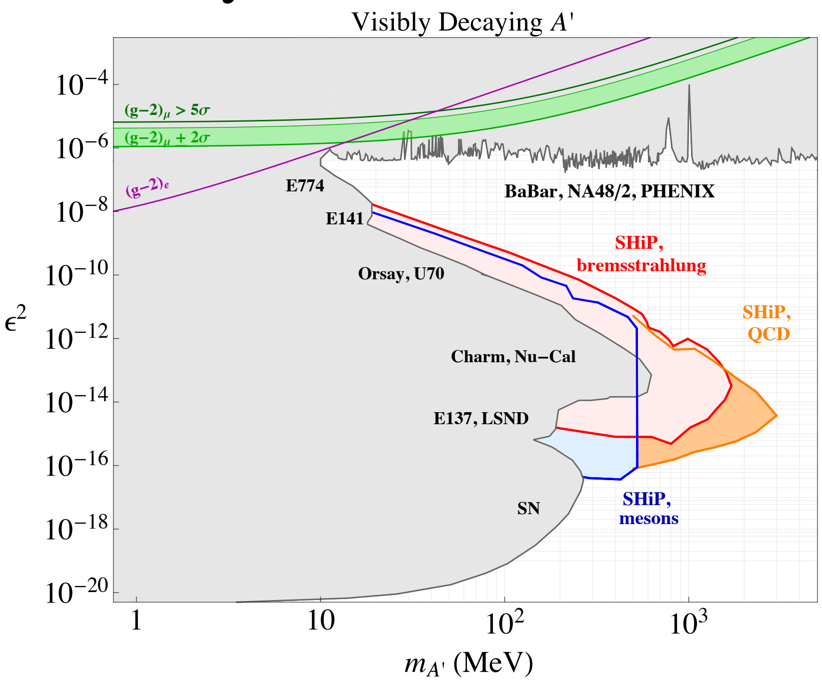
The SHiP experiment
(as implemented in Geant4)

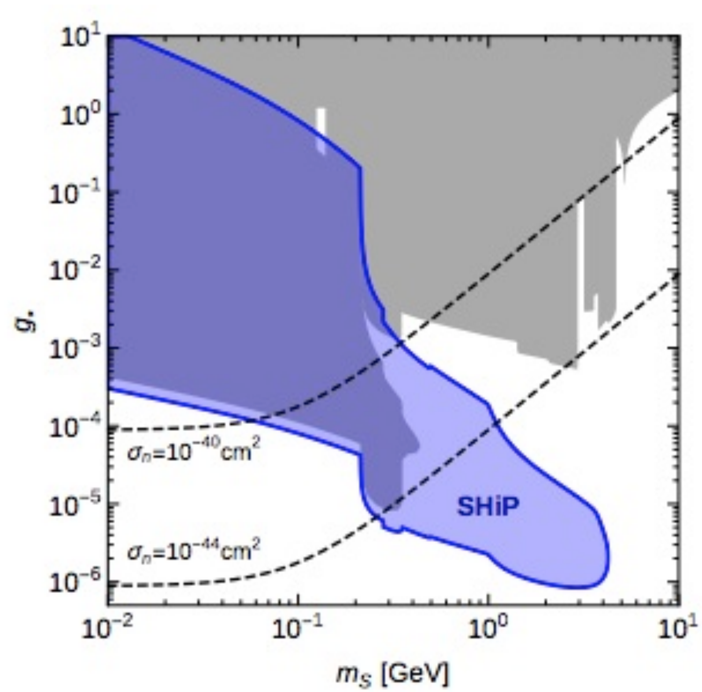


See e.g. A. Golutvin presentation, CERN SHiP symposium, 2015

SHiP sensitivity to vector and scalar portals

- SHiP will collect 2×10^{20} protons of 400 GeV dumped on target
- Sensitivity to dark vectors is via the unflavored meson decays, and through direct production, pp → … V → …… l^+l^-
- Sensitivity to light scalar mixed with Higgs is via B-meson decays, b → s + Scalar → … $\mu^+\mu^-$





Details can be found in the white paper, 1505.01865, Alekhin et al.