Dark Matter search at fixed target

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Light-DM searches: motivations

If DM is a thermal relic from hot early universe, can hunt for it in particle-physics searches:

search for non-gravitational interactions DM-SM

a mediator might exist, which let SM and DM fields interact

Consider possible mediator-SM interactions, limit to lowest-dimension operators:

Scalar,	L ~ $\mu\, SHH + \lambda\, S^2 HH$ → Modified H properties → suited for LHC	
Pseudoscalar portal,	L ~ $\psi\, \gamma^\mu \gamma^5\, \psi\, d_\mu a$	→ Axion or ALP's
Neutrino portal,	L ~ Y_N LH N	→ Sterile neutrinos
Vector portal,	L ~ $\varepsilon q\, \psi\, \gamma^\mu\, \psi\, A_\mu$	→ Dark photons

Each portal can involve different interactions → model dependency, freedom

E.g.: vector mediator (dark photon) + scalar DM, a secluded $U(1)_D$ sector mixing with SM U(1):

$$\mathcal{L}_{mix} = \epsilon F'^{\mu\nu} F_{\mu\nu} \qquad \mathcal{L}_{int} = A'_\mu (\epsilon e \mathcal{J}^\mu_{EM} + g_D \mathcal{J}^\mu_D) \qquad \mathcal{J}^\mu_D = i\varphi^* \partial^\mu \varphi + c.c.$$

E.g.: vector mediator (dark photon) + Dirac DM, a broken $U(1)_D$ sector

$$\mathcal{L}_{int} = A'_\mu \chi^\dagger_+ \bar{\sigma}^\mu \chi_-$$

E.g.: vector mediator (dark photon) of a U(1) gauge with charge=B-L

etc.

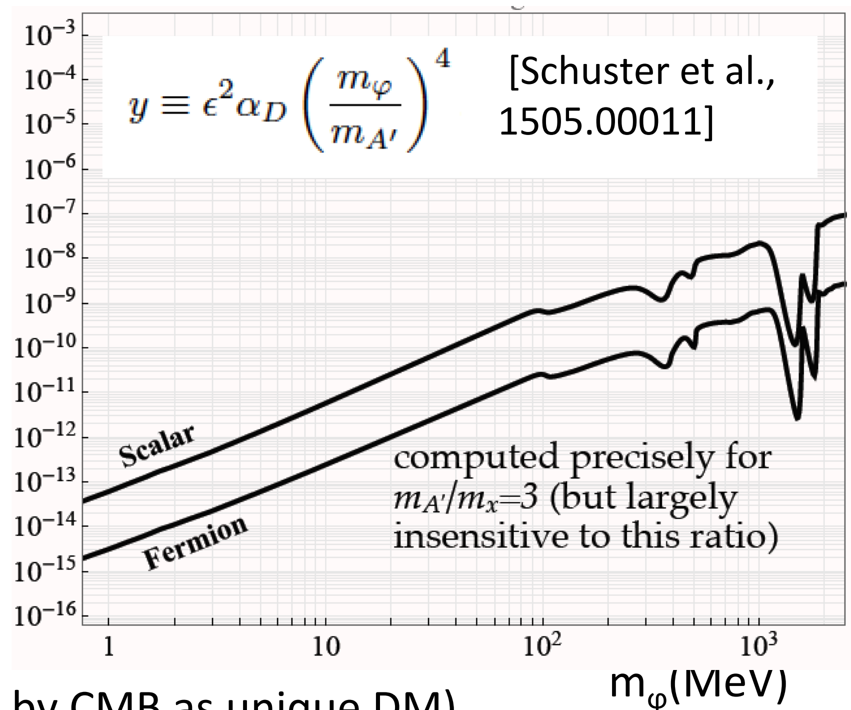
Light-DM searches: motivations

Can (any of) these models explain observed DM?
E.g., A' + scalar DM: relic density ruled by $\sigma(\varphi\varphi^* \rightarrow e^+e^-) \sim y/m_\varphi^2$, $y \equiv \epsilon^2 \alpha_D \left(\frac{m_\varphi}{m_{A'}}\right)^4$
Match w DM density: $<\sigma v_{rel}> \sim 3\ 10^{-26}\ cm^3 s^{-1} \sim 1/20 TeV^2$?

OK if m_φ~20 TeV/$y^{1/2}$

Thermal origin working for a BROAD range of mediator and DM masses, guiding exp. searches:

- TeV DM, O(1) couplings: WIMP's searches
- Sub-eV DM, y ~ 0(10^{-26}): Axion/ALP or γ-A' mix
- **MeV-GeV DM → this talk**



E.g.: vector portal matches with observed DM if:
- Thermal relic of a scalar DM (Dirac DM ruled out by CMB as unique DM)
- Thermal relic of Dirac DM + soft $U(1)_D$ breaking
- Evolution of asymmetric primordial particle-antiparticle density of scalar or Dirac DM

DM searches: experimental status

More than 20 years of experimental effort in the GeV-TeV (WIMP) range

Various constraints from direct searches

Sensitivity to halo below 1 GeV ($v \sim 10^{-3}$) limited:

threshold in nuclear recoil energy

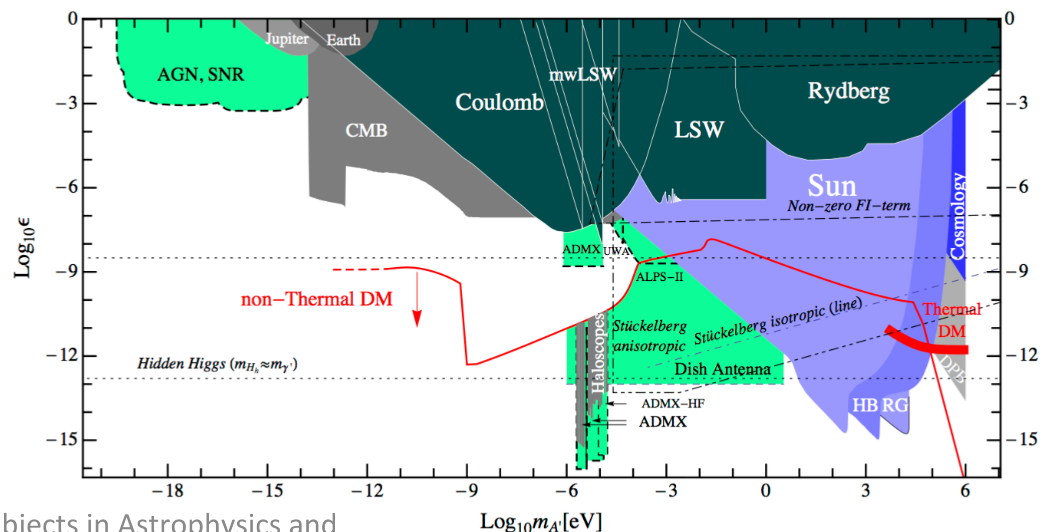
LHC closing the gap, too: see M. Antonelli's talk

Sub-eV: usually a by-product of axion or ALP's searches

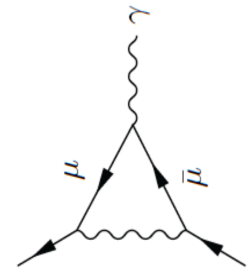
a sub-eV A': lifetime longer than age of universe, can explain DM by itself

Approaching expected parameters allowing A' as sole DM from thermal or non-thermal origin:

- **Cosmological arguments**
- **Astronomical observations**
- **Experimental limits**
- **Future experiments**



Why MeV-GeV? Hints/suggestions



$(g\text{-}2)_\mu$ anomaly 3-σ discrepancy with expectation
might be explained by A' contribution
expect 10 < $M_{A'}$ < 100 MeV and $\varepsilon^2 \sim 10^{-6}$

e+/e- cosmic-ray eccess (PAMELA, Fermi, AMS-02)
if not due to PULSAR's, might be due to $\varphi\varphi^* \rightarrow A' \rightarrow e^+e^-$
spectrum measured by AMS favors $M_{A'}$ ~ 500 MeV, for multiple-hadron production

CDMS-II 3 events on top of expected background of 0.62 after null from LUX & XENON
WIMP mass within (6.5,20) GeV @68% CL, σ(WIMP – Nucleon) ~ 10^{-41} cm^2
Higgs and Z mediators disfavored, cross section might be enhanced by a GeV-Mass A'

The DAMA-Libra (and COGENT) effect
a few-GeV DM scattering might be enhanced by A' exchange

Others, more details in V. Kozhuharov talk

Searching in the MeV-GeV region is a justified experimental effort

MeV-GeV DM: experimental guidance

MeV-GeV states with ε couplings down to 10^{-8}—10^{-5} interesting to be probed
ranging between short-lived and long-lived light states

Fixed target can yield A' orders of magnitude more than colliders for low-dimension Op's [Batell arXiv:0906.5614]
OK, will have to consider acceptances, backgrounds, the production mode, etc..

Vibrant field indeed, with competition of:
high-energy proton colliders
low-energy e^+e^- colliders
fixed target experiments with proton, e^- and e^+ beams

Vector portal: production mechanisms

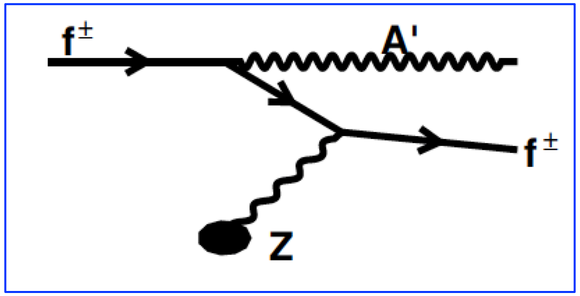
Bremsstrahlung from $e^{\pm}$ beams (thin target):

pros: if $m_e << M_{A'} << E_{beam}$, clear signature

$E_{A'} \sim E_{beam}$ and $\theta_{A'} \sim (M_{A'}/E)^{3/2}$

pros: yield scales with Z^2

cons: yield falls with $1/M_{A'}^2$

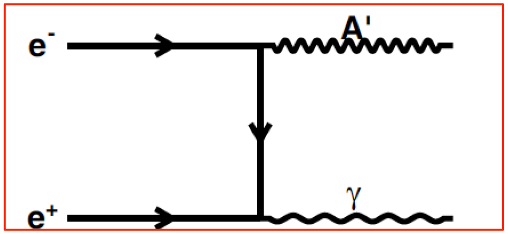


e^+e^- annihilation from e^+ beams

pros: clear signature after photon matching

pros: yield sizeable up to threshold

cons: yield/atom scales as ~ Z

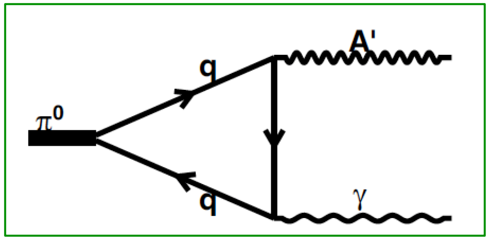


Meson decays:

pros: clear signature if accompanying γ detected

pros: yield up to threshold

cons: assume A' coupling with quarks



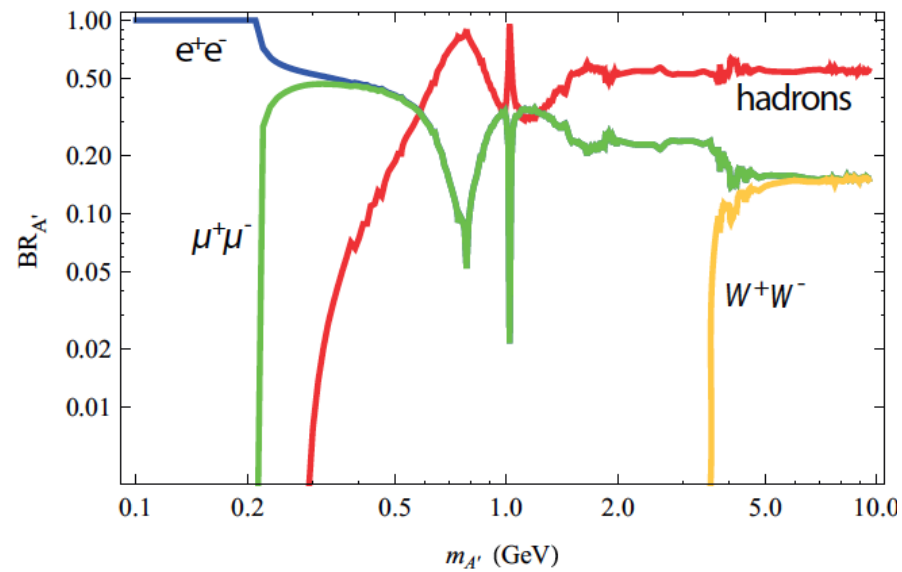
Hard bremsstrahlung from proton beams

pros: can be calculated accurately, allow testing $M_{A'} > M_{\eta}$

at high pt scattering on partons dominates, but difficult to be estimated with accuracy

Vector portal: decay mechanisms

Visible decays, assuming universal coupling with em current: $A'_\mu(\epsilon e \mathcal{J}^\mu_{EM} + g_D \mathcal{J}^\mu_D)$



e^+e^- decay dominant for $2m_e < M_{A'} < 210$ MeV

$\mu^+\mu^-$ decay ~ as frequent as e^+e^- for heavier A'

Hadronic modes as in SM e^+e^- scattering

[if $M_{A'} < 2\, m_e$, A' → 3γ, A' practically stable]

$M_{A'} = 0$ is a special case, see later

If A' coupled to a DM particle φ with $M_\varphi < M_{A'}$:
- **BR(A'→φφ) ~ 1 ("invisible" decays)**
- **A' lifetime significantly dominated by α_D, expected of O(1)**
- **BR(e^+e^-, $\mu^+\mu^-$) suppressed by a factor ε^2**

Vector portal: visible searches

Assume A' decays to SM particles with universal coupling εe, **go di-lepton bump hunting**

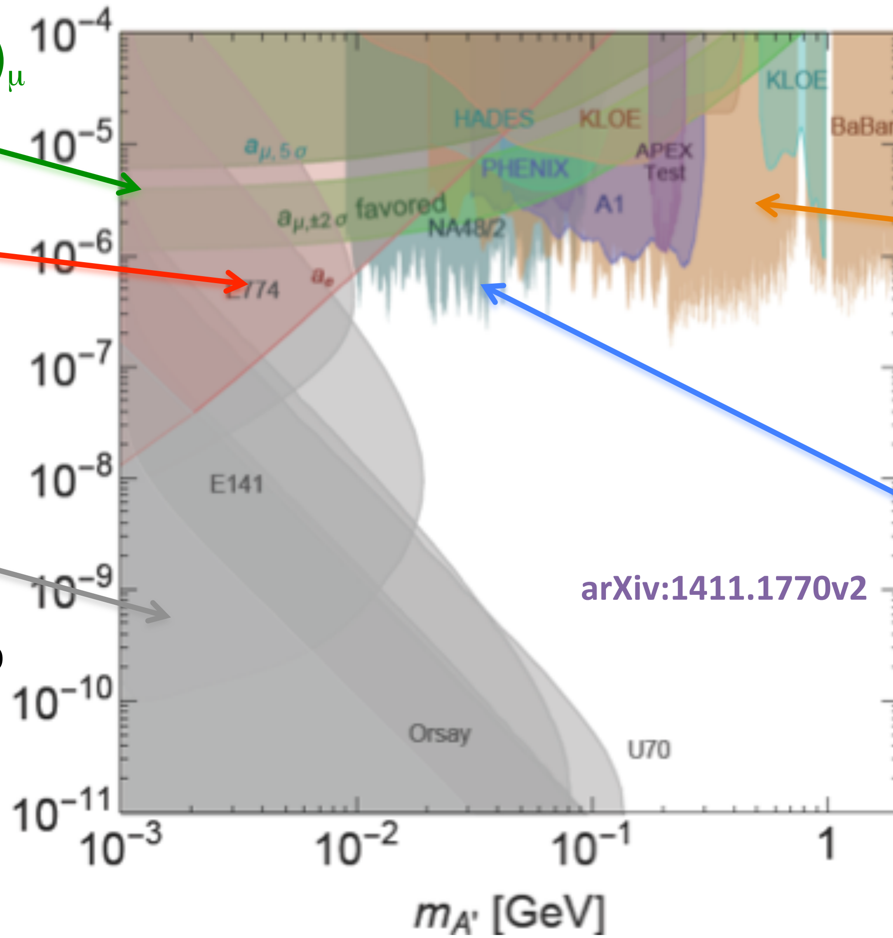
- **model dependent: no A'→φφ**

Favored to explain $(g-2)_\mu$

Indirect from $(g-2)_e$

Fixed target expts:

- p or e beams
- $e^+e^-, \mu^+\mu^-$ after dump from strahlung or meson decays



Expts at e^+e^- colliders (Babar):

- $\Upsilon(4,3,2S) \rightarrow \gamma A' \rightarrow \gamma e^+e^-, \gamma\mu^+\mu^-$
- Assume coupling to quarks

Prompt meson decays from fixed target (NA48/2):

- $K^\pm \rightarrow \pi^\pm\pi^0$, $\pi^0 \rightarrow A'\gamma \rightarrow e^+e^-\gamma$
- Assume coupling to quarks

A' visible searches (beam dump)

Assume A' decays to SM particles with universal coupling εe, **go di-lepton bump hunting**

Fixed target expts:

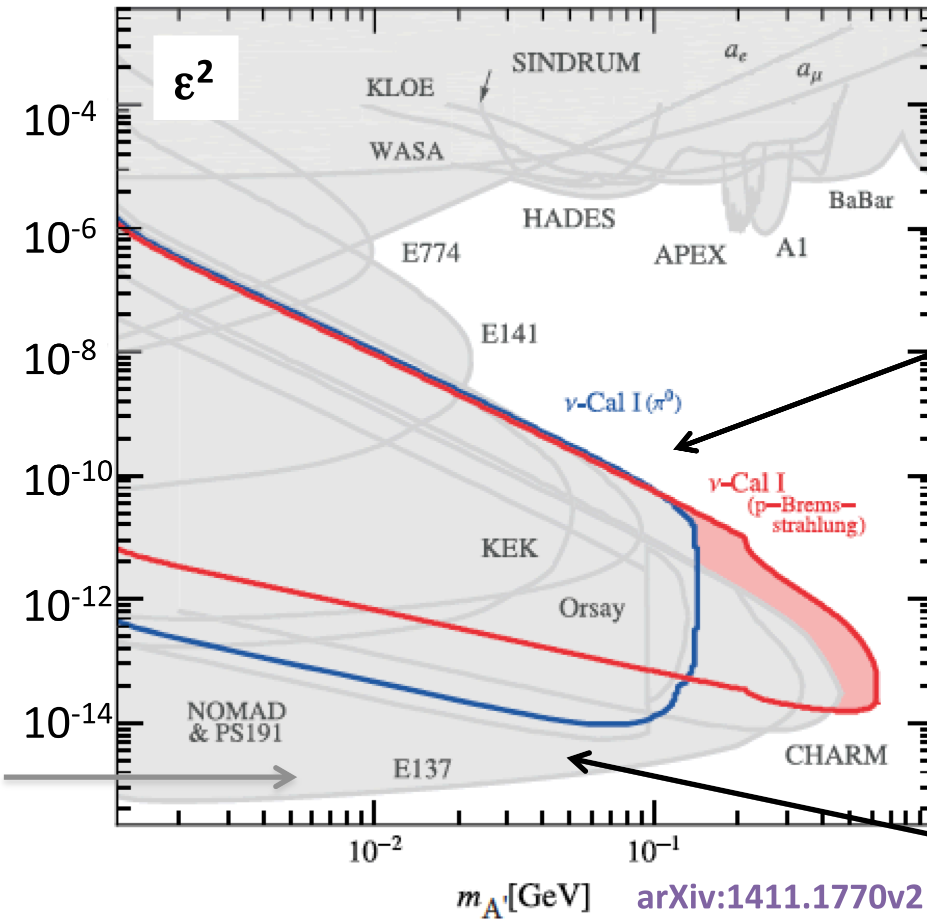
- e beams: KEK, E141, E137, E774, Orsay
- p beams: CHARM, PS191, Nomad, ν-CAL

ν-CAL at U70:

- 2 10^{18} POT on Be target
- $e^+e^-,\mu^+\mu^-$ after dump from strahlung or meson decays

Lowest couplings, E137 @ SLAC 20 GeV e LINAC

- **10^{20} e on Al target**



arXiv:1411.1770v2

From above, A' decay before sensitive area: need compact dump $N \sim \varepsilon^2 e^{-(D/\lambda)}$

From below, can't contain A' decays, $N \sim \varepsilon^2 [1-e^{-(L/\lambda)}] \sim \varepsilon^2 \Gamma(M)\, M/p\, L \sim \varepsilon^4$

Present/future of visible searches

"From above":

- Belle-II can improve on Babar, but irreducible bkg will limit sensitivity
- NA62 can improve on NA48/2 in particular thanks to a better inv. mass resolution
- ATLAS, CMS (not shown)
- LHCb (not shown)

Planned fixed-target experiments using A'-strahlung (see V. Kozhuharov):

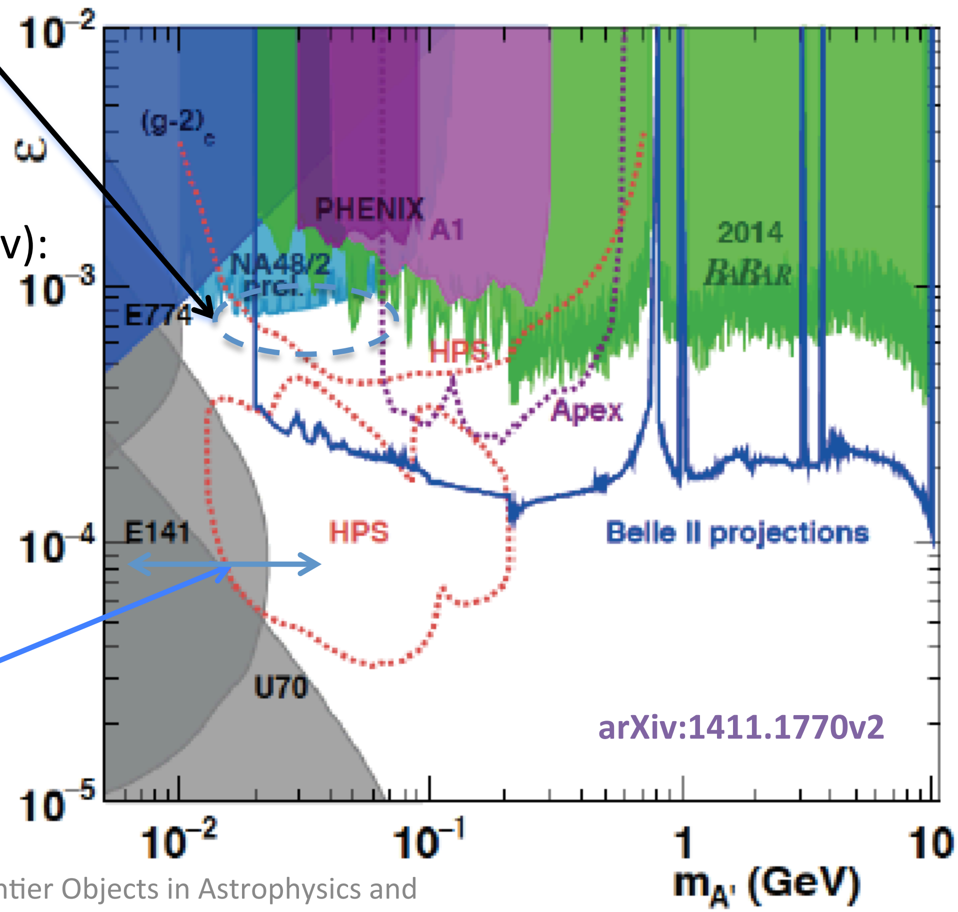
Apex @ JLAB

- 10^9 events, detect e^+e^- pairs
- Run in 2018

HPS @ JLAB

- Running since 2015
- Optimizations for short- and long-lived scenarios

MAGIX @ MESA Mainz

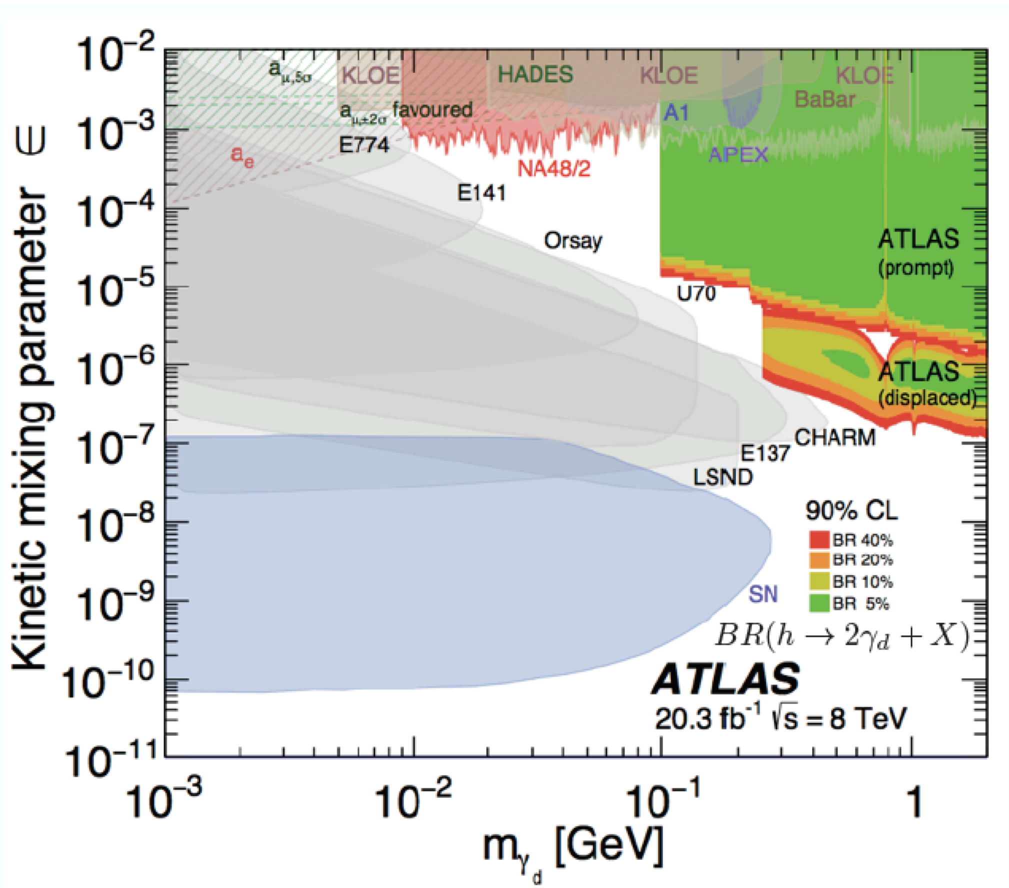


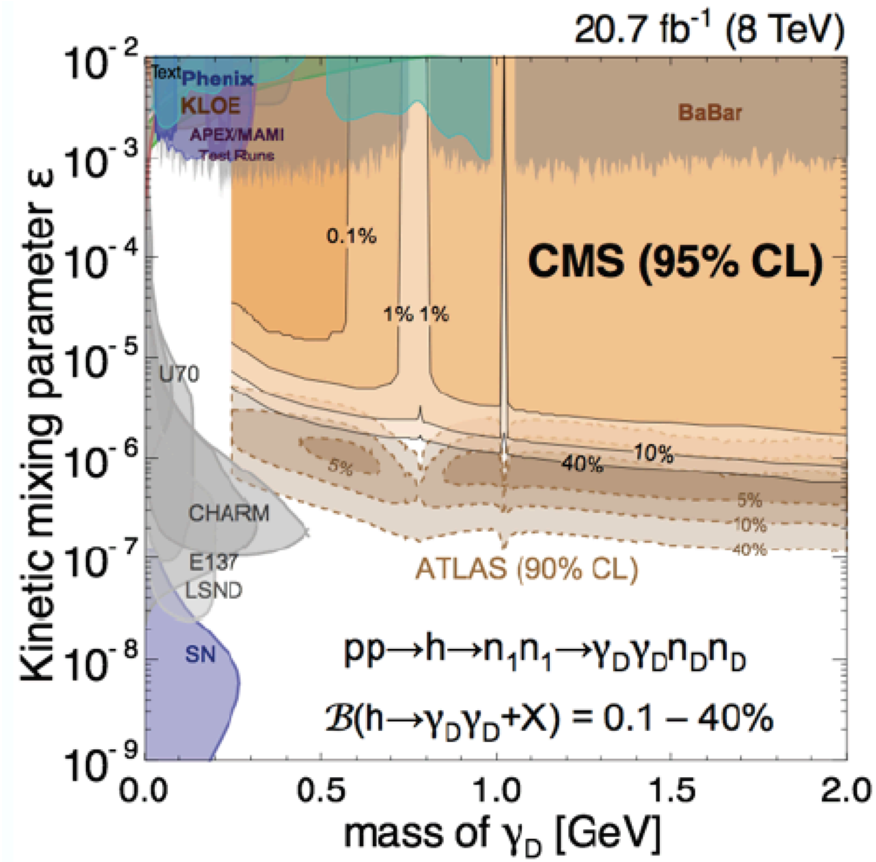
Present/future of visible searches

"From above":

ATLAS, **CMS** from Higgs 4-lepton modes: prompt and displaced vertices

After run-II improvements: first results @ end of 2016 [Beecham, dark sectors WS 2016]

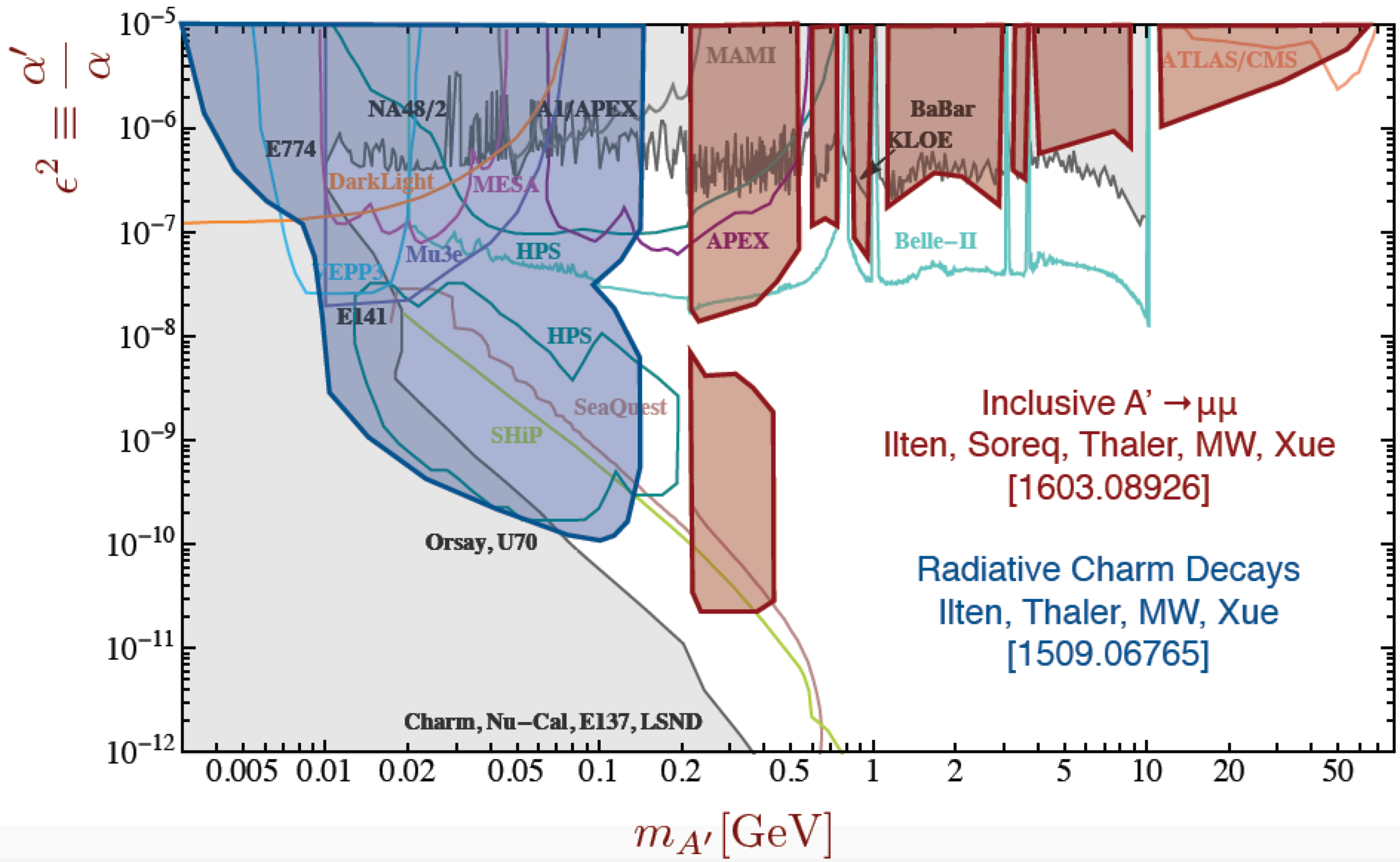




Present/future of visible searches

"From above":

LHCb from D*→D0 A', A'→2-lepton modes: prompt and displaced vertices
future sensitivity (Run-III), triggerless setup



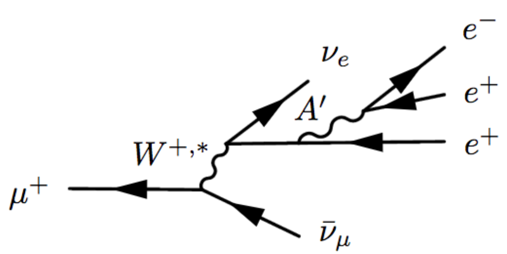
Present/future of visible searches

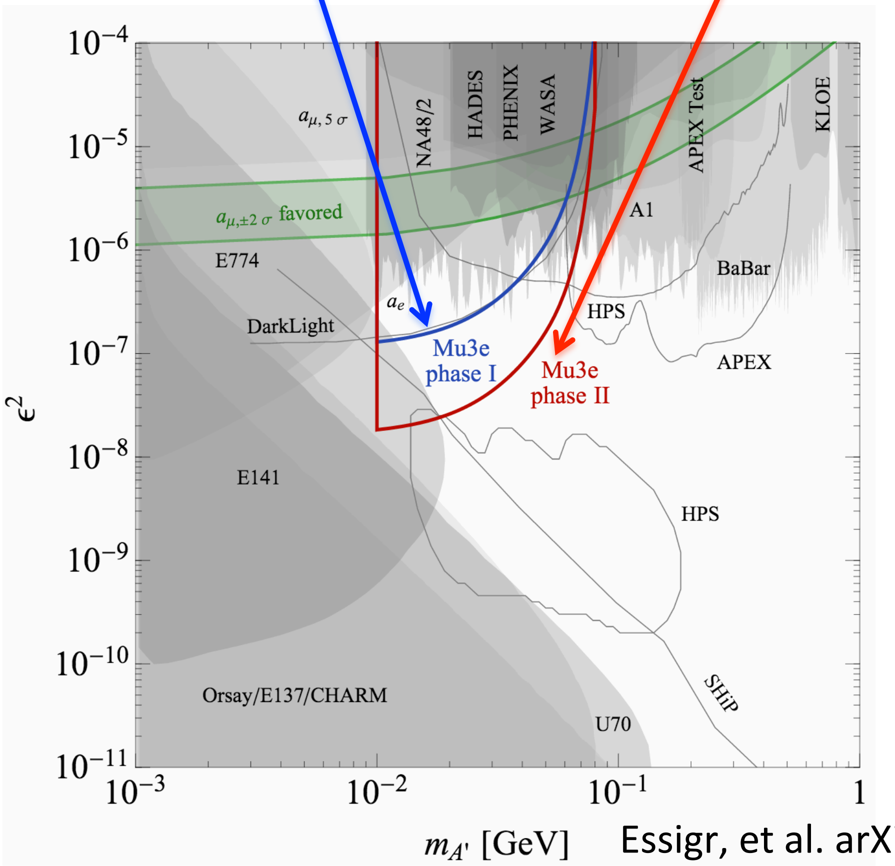
"From above":

The Mu3e experiment at PSI, should probe 10^{15} μ decays by 2016 ($5.5\ 10^{16}$ by 2018)

It can improve in the NA48/2--Babar region

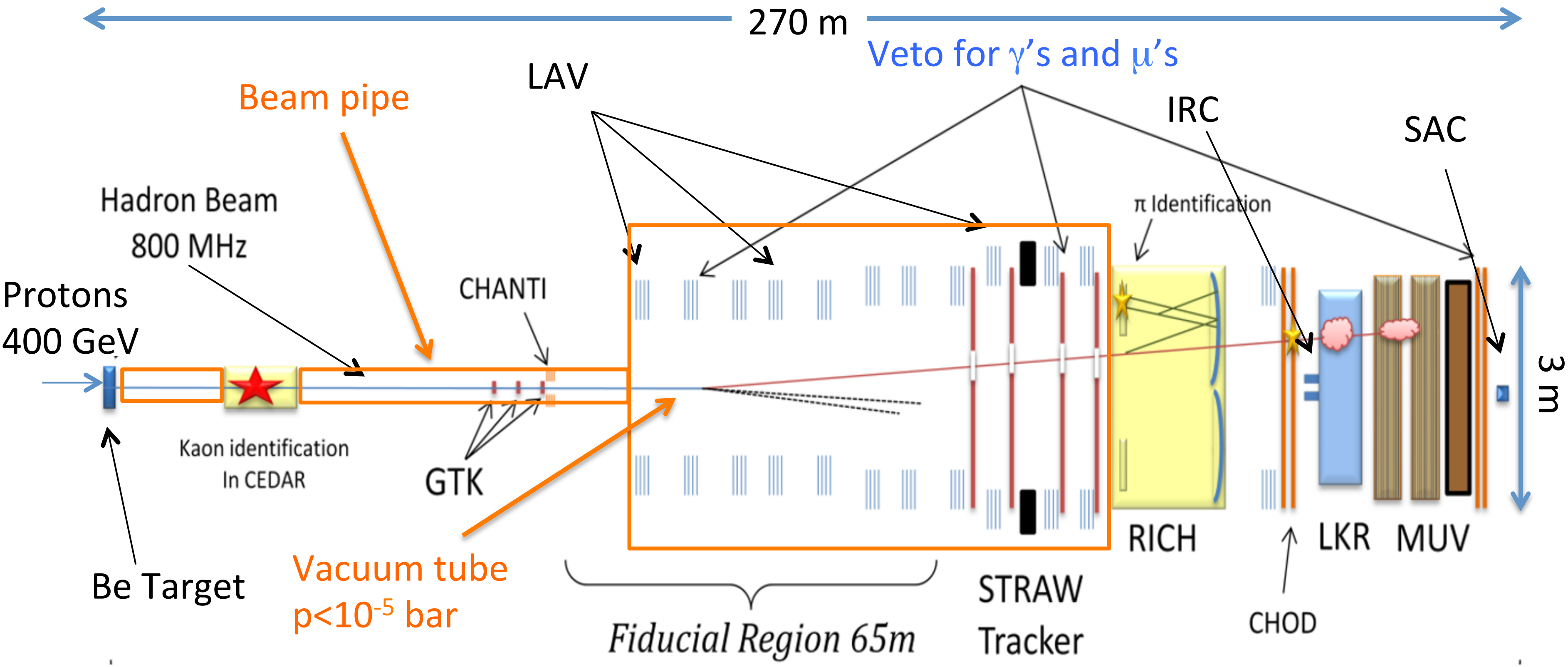
Probing the transition





Essigr, et al. arXiv:1411.1770v2

Present/future of visible searches: NA62



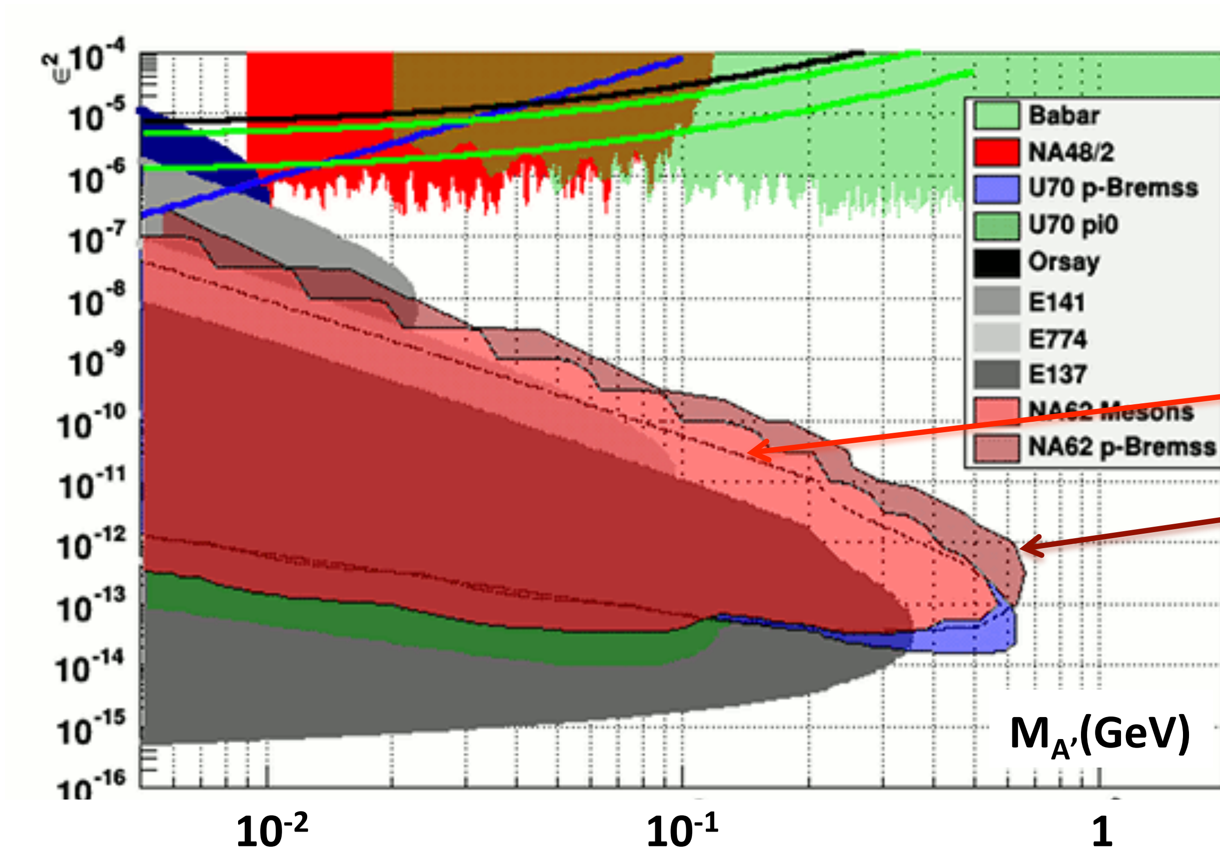
3×10^{12} ppp, 750 MHz on beam spectrometer (6% K+), ~10 MHz downstream, O(10 KHz) final trigger rate

beam spectrometer (GTK), efficient γ vetoes (LAV, LKr, IRC, SAC), redundant PID

Present/future of visible searches: NA62

"From below", many new searches planned/proposed/approved

NA62 @ CERN SPS can improve on U70, with ~2 10^{18} 400-GeV POT in 2016-2018



Expected 90% CL UL for A'→l^+l^- after 2 years of data taking (zero-background)

A' from meson decays vs

A' from p-Bremsstrahlung

Acceptance and trigger efficiency included

Riv. N. Cim. 38 (2015) 10, 449 + my evaluations for NA62

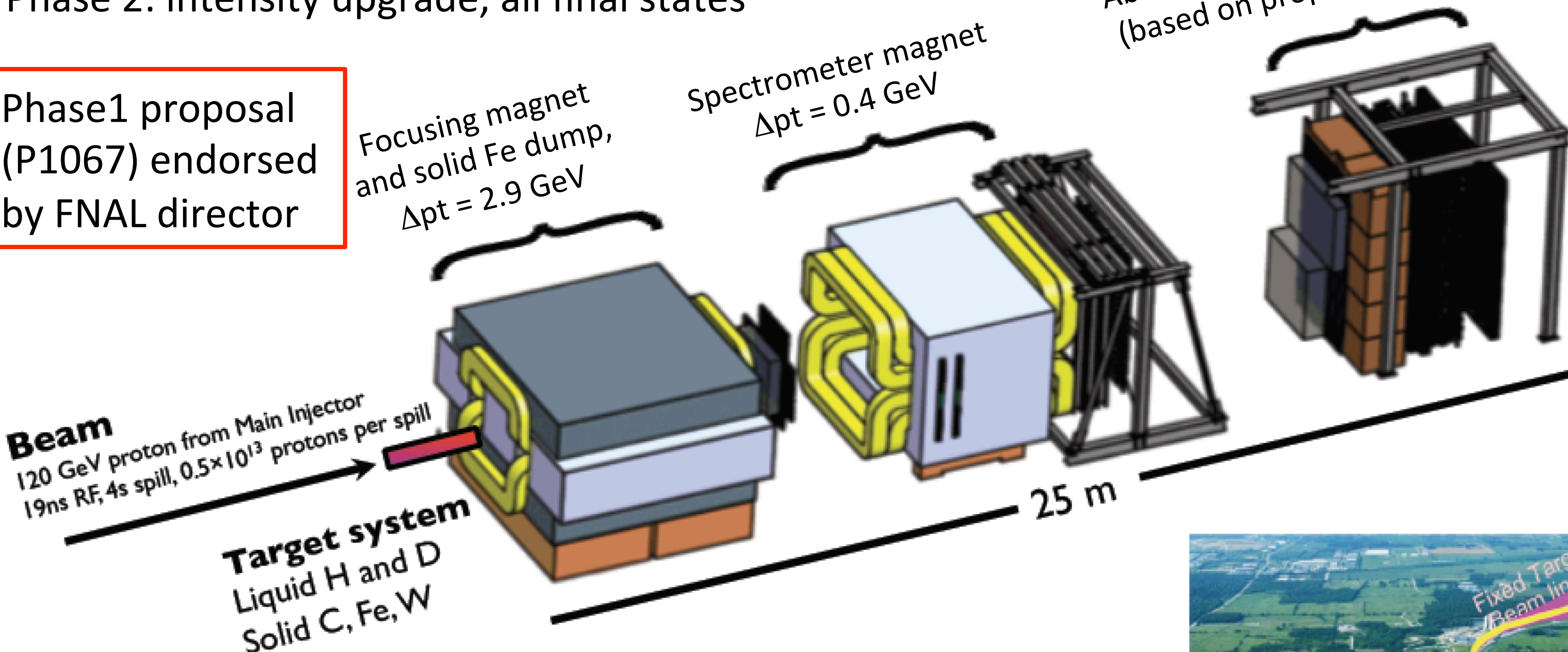
Future visible searches: SeaQuest @FNAL

"From below", **SeaQuest**: 120-GeV p beam from FNAL main injector

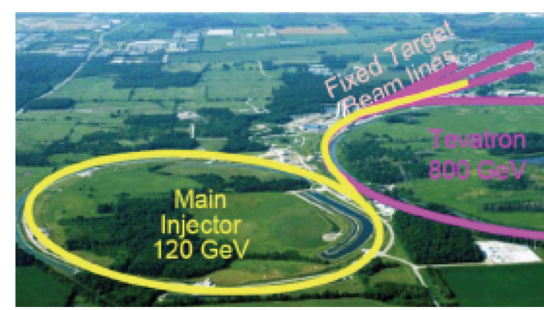
Phase 1: $\mu+\mu-$ displaced pairs, **1.44 10^{18} POT** in 2017-2019

Phase 2: intensity upgrade, all final states

Phase1 proposal (P1067) endorsed by FNAL director



- Capture most beam in beam dump mode: p+Fe collisions!
- Parasitic run mode possible with other experiments, E906/E1039



Ming Liu @ Dark Sectors 2016

Future of visible searches: SHIP @ SPS

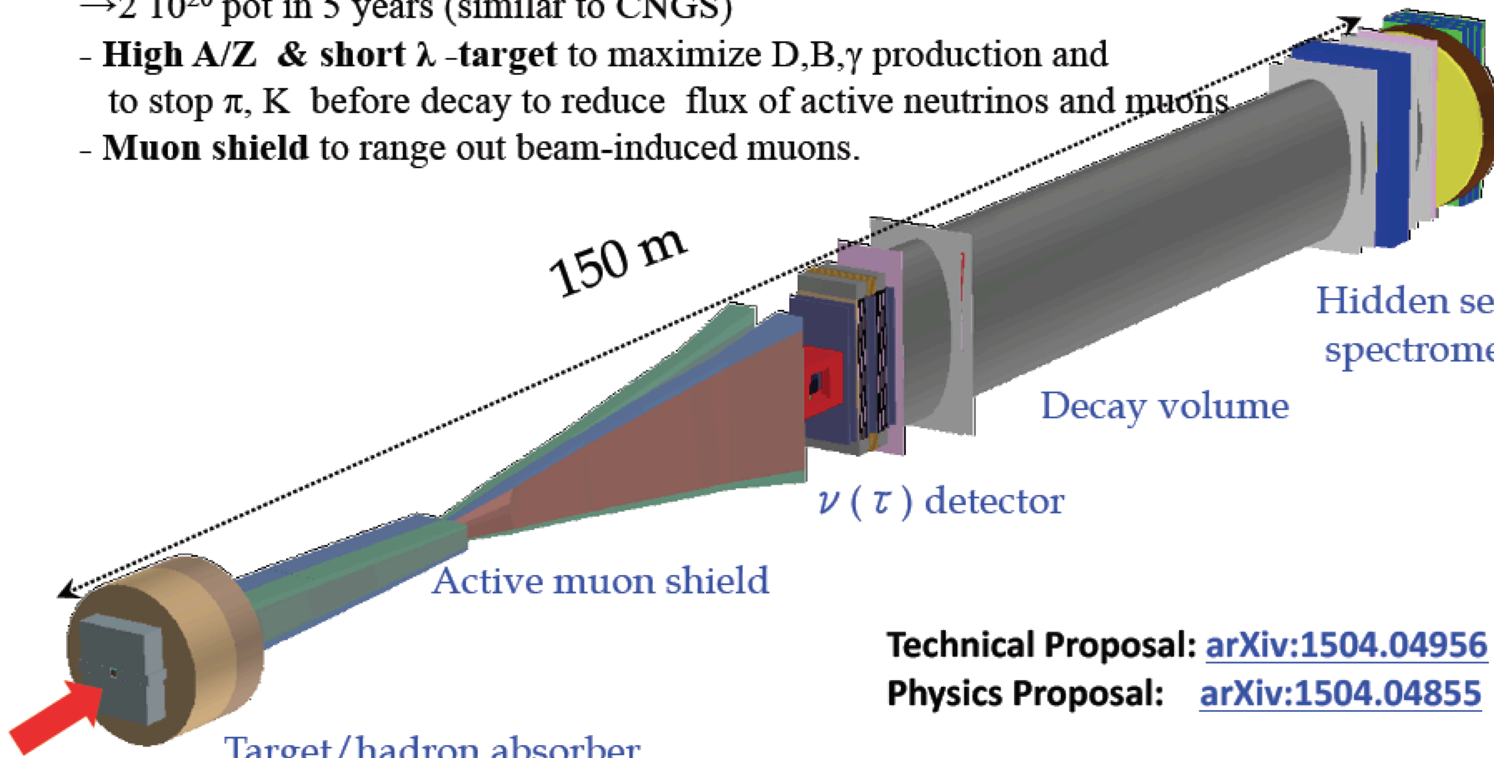
"From below", hidden-sector experiment proposed: SHIP at CERN SPS

Proton fixed-target (beam dump like) experiment at the CERN SPS

- **SPS:** 4×10^{13} proton on target /7s @ 400 GeV , 1 sec spills (slow extraction)

  $\rightarrow 2\ 10^{20}$ pot in 5 years (similar to CNGS)

- **High A/Z & short λ -target** to maximize D,B,γ production and to stop π, K before decay to reduce flux of active neutrinos and muons
- **Muon shield** to range out beam-induced muons.



Technical Proposal: arXiv:1504.04956
Physics Proposal: arXiv:1504.04855

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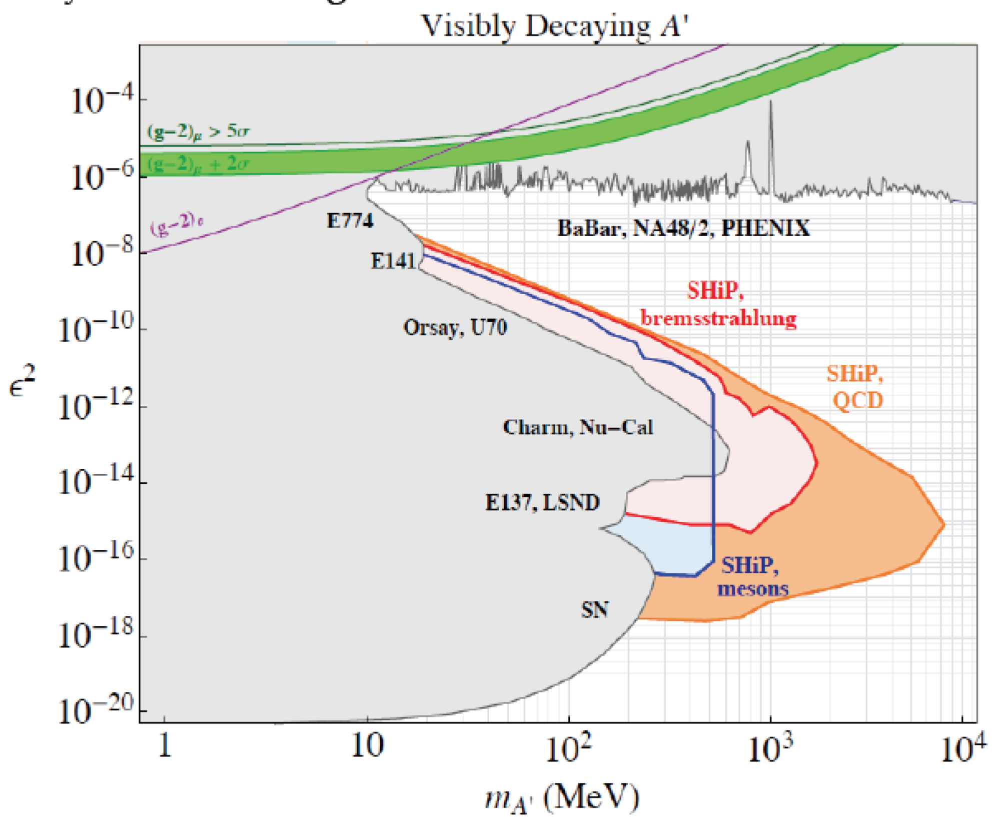
G. Lanfranchi @ Dark Sectors 2016

Future of visible searches: SHIP

Proposal to start data taking in 2026, supported by SPS Committee and Research Board

CERN management appointed a "Physics Beyond Colliders" study group to give an input to the 2018 European Strategy for Particle Physics, see A. Golutvin @ Dark Sectors 2016

$2\ 10^{20}$ pot in 5 years of running

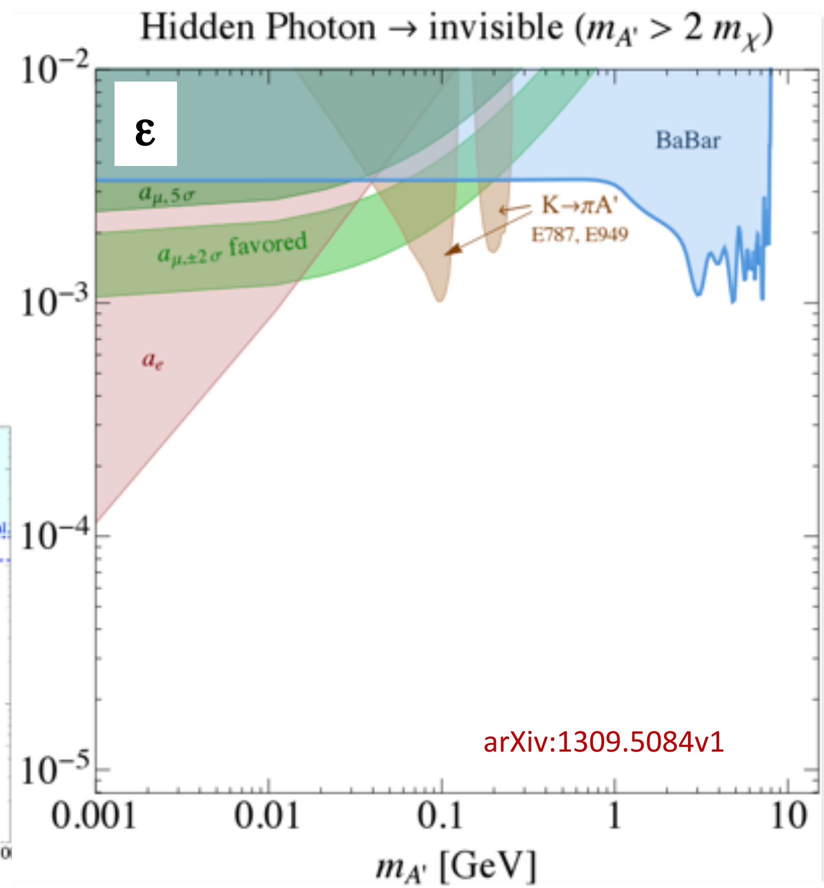


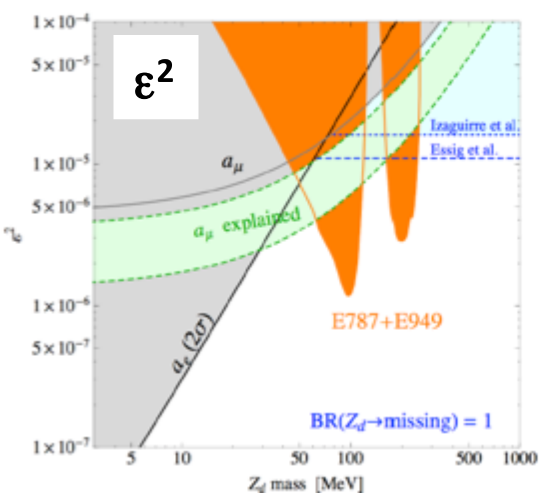
Invisible searches

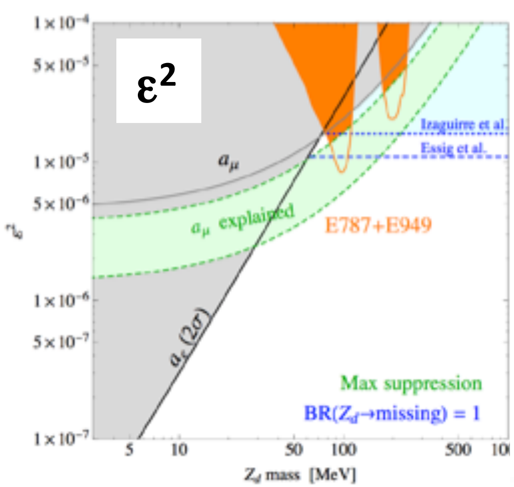
If A' coupled to a DM particle φ with $M_{\varphi} < M_{A'}$: short lifetime, beam dump searches evaded

Scarce information for invisible searches

- **Babar '08 (ArXiv:0808.0017, no paper):**
  - **$e^+e^- \rightarrow \Upsilon(3S) \rightarrow \gamma A'$, tag A' by γ detection**
- **E787/E949 @ BNL:**
  - **$K^+ \rightarrow \pi^+ A'$, model dependent**
  - **($\gamma A'$ kinetic mixing, less stringent if Z-mixing)**







Invisible searches: annihilation

Approach to model-independent A' invisible searches

1. Positron annihilation: $e^+e^- \rightarrow \gamma A'$, tag A' by γ detection, bump hunting on missing mass

exploit cross section enhancement toward threshold (control A'-shape dependence)

PADME@LNF (approved):

see V. Kozhuharov's talk in this session

VEPP-3 @ Novosibirsk (proposed):

E_{e+} = 500 MeV, L = 10^{33} $cm^{-2}s^{-1}$, T = 10^7 s

$e^+e^- \rightarrow A'\gamma$, 4(20) nb $\varepsilon^2/10^{-6}$@ $M_{A'}$ = 15(20) MeV

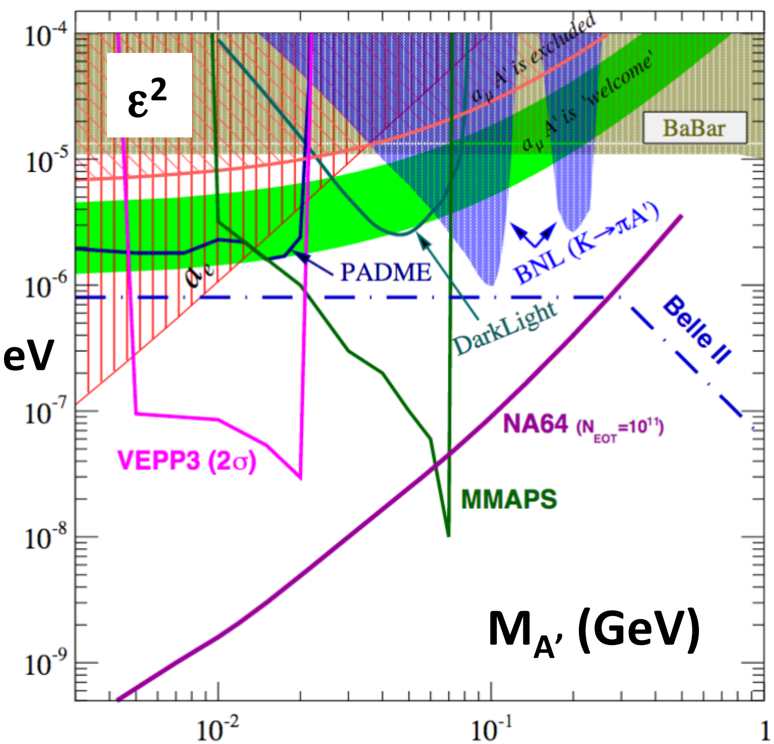
MC study, considering SM backgrounds:

$e^+p \rightarrow e^+p\gamma$

$e^+e^- \rightarrow e^+e^-\gamma$

$e^+e^- \rightarrow \gamma\gamma$

$e^+e^- \rightarrow \gamma\gamma\gamma$



Propose to reuse CsI(Tl) crystals from CLEO + by-pass in straight VEPP section (2020)

Invisible searches: E_{miss}

Approach to model-independent A' invisible searches

2. Electron beam A'-strahlung: $e^- N \rightarrow e^- N A'$, detect e^-, A'-signal has missing energy $E_{miss} > 0$

if an E_{miss} signal is found, have to guess $M_{A'}$ by distribution shape..

NA64@CERN SPS (running):

see V. Kozhuharov's talk in this session

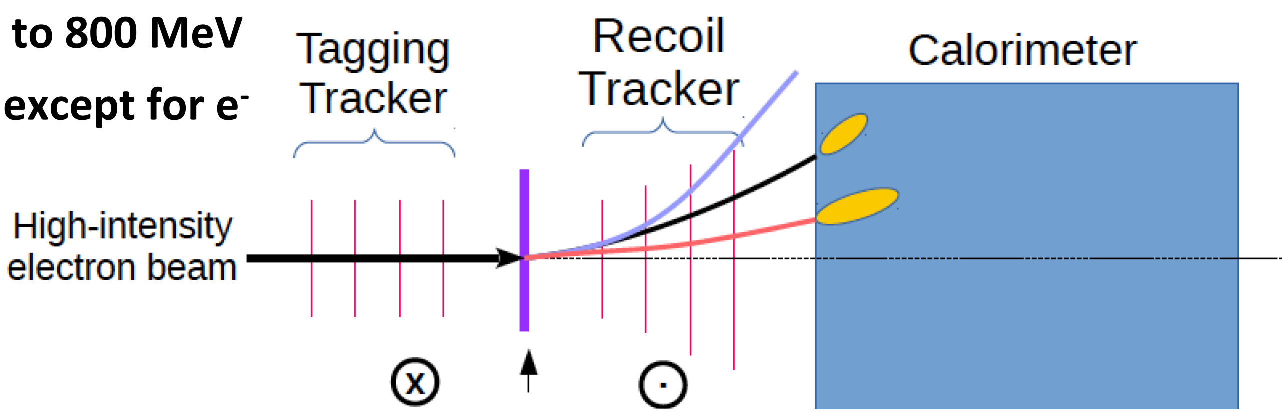
LDMX @ LCLS-II of SLAC (proposed, installation 2018/19, operational in 2020/21):

10^{15-16} 4-GeV e^- on a 0.1 X_0 W target (from the SCRF LINAC, parasitic to the X-ray FEL)

Track e^- before/after A'-strahlung

Select recoil pt from 80 to 800 MeV

Expects no calo energy except for e^-



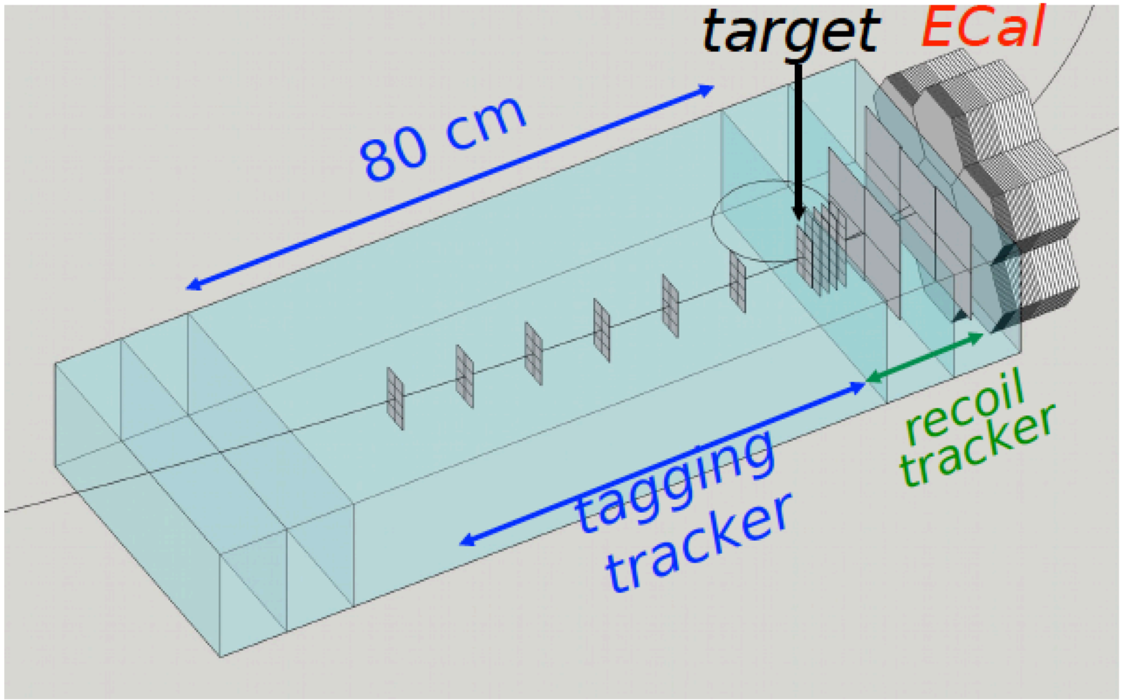
Invisible searches: LDMX @ SLAC

Background rejection based on calorimeter granularity (shower shape)

Si-W calorimeter from High-luminosity-LHC R&D for CMS Endcaps

Low-mass (0.5%X_0/layer), 100x100 μm-pixel Si-based tracking: NA62 technology, σ_t ~ 1ns

Trigger to reduce rate from 1 GHz to 750 KHz full TDC-based readout of Ecal + Trackers



Invisible searches: future sensitivities

Next few years: sensitivity improvement, sensitivity reaching relic-density interesting region

PADME @ LNF, approved, 2017-

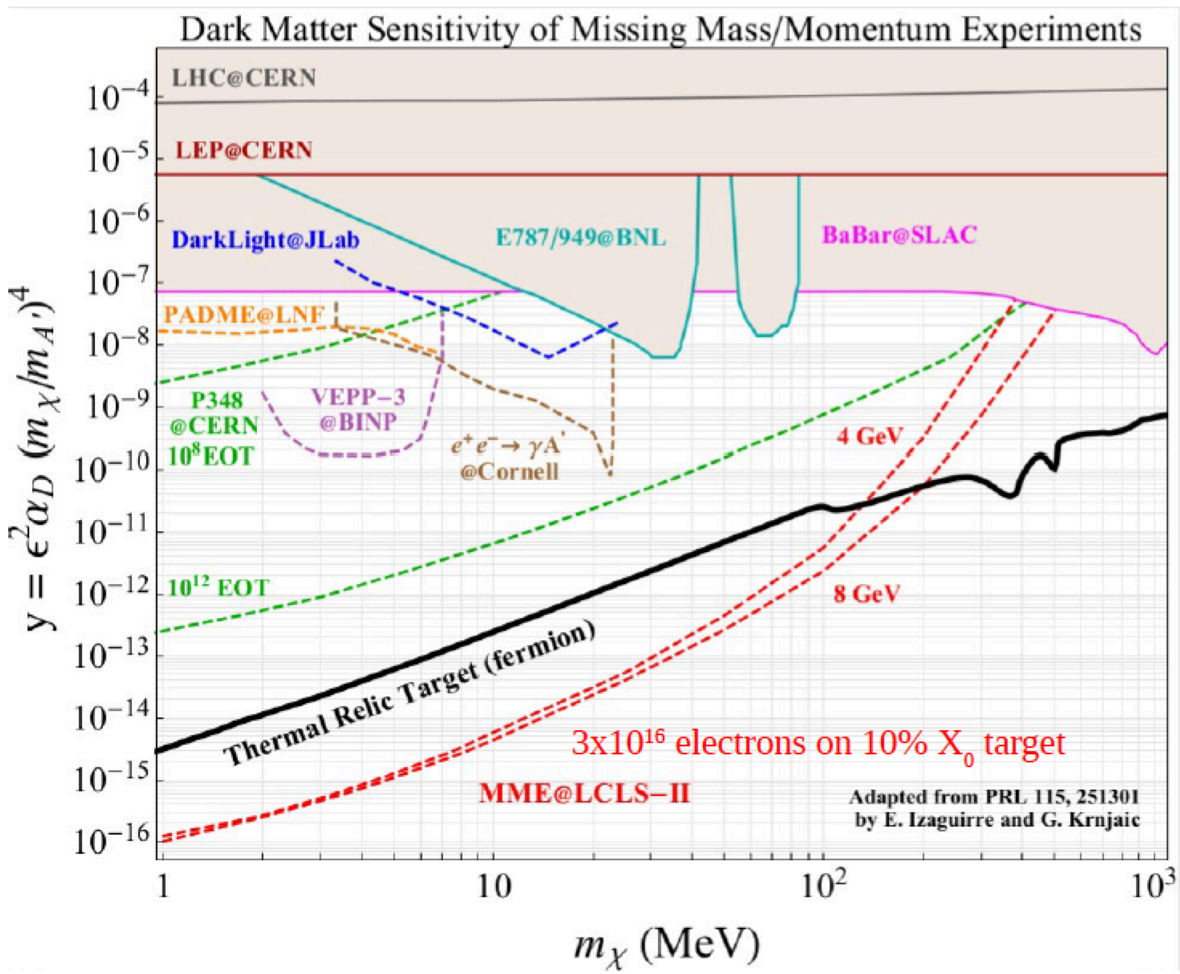
MMAPS @ Cornell, not funded

DarkLight @ Jlab, concept

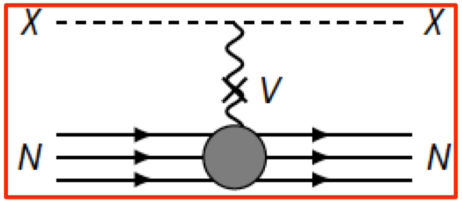
NA64 @ CERN, running

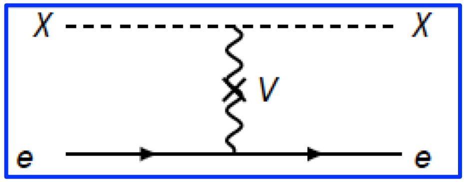
VEPP-3 @ BINP, uncertain

LDMX @ SLAC, proposed, ~2020



DM searches: produce and detect it





If decay A' → $\varphi\varphi^*$ is open, can detect φ?

Production: meson decay or electron/proton beam A'-strahlung

Detection: via nucleon interaction or scattering on electrons

alike ν-nucleon neutral current elastic scattering

can be a by-product of neutrino experiments indeed

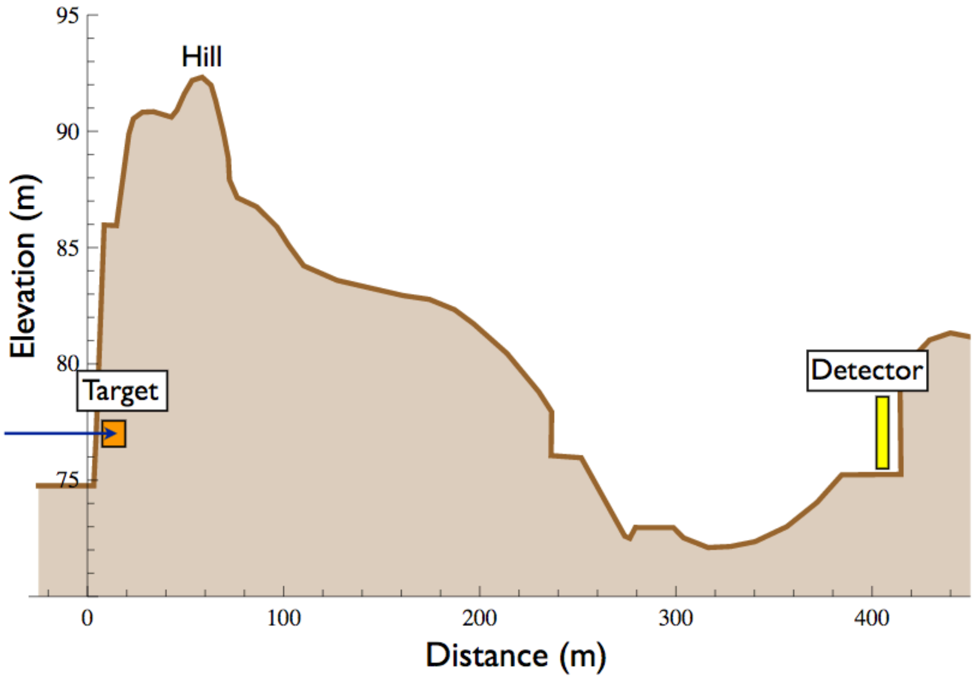
Model dependency, caveats:

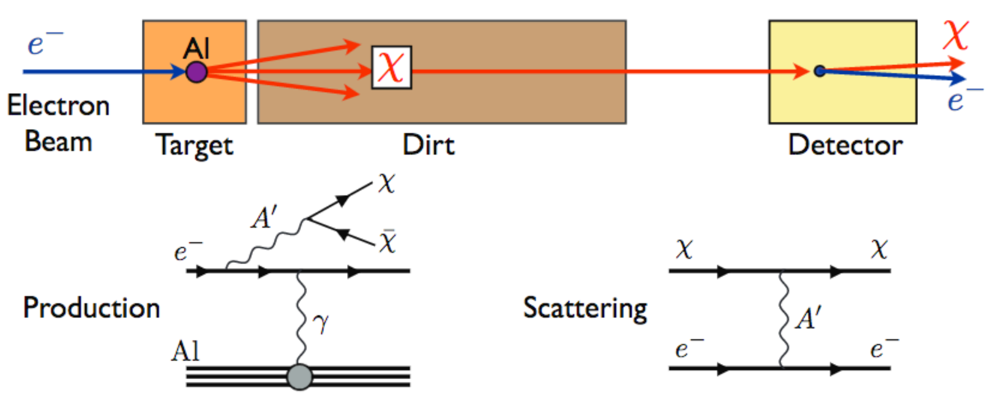
1. **assume only one DM φ, if $\varphi \rightarrow \varphi_2$ acceptance drops dramatically**
2. **DM-nucleon scattering is model dependent**

Under above assumptions, experiments sensitive to $\varepsilon^4\alpha_D$ with dependency on $M_{A'}$ and M_φ

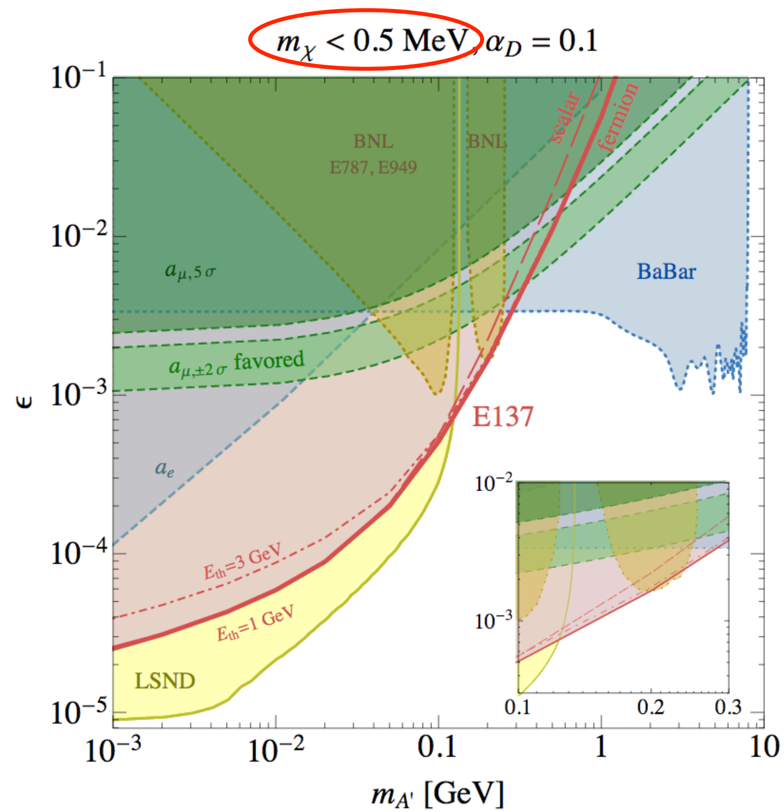
DM searches: re-analysis of E137@SLAC

A total of 30C 20-GeV e- on Al target + beam dump (search for Axions → e+e- ,photinos, etc.)





Limit depends on M_χ and α_D



Batell, arXiv:1406.2698v2

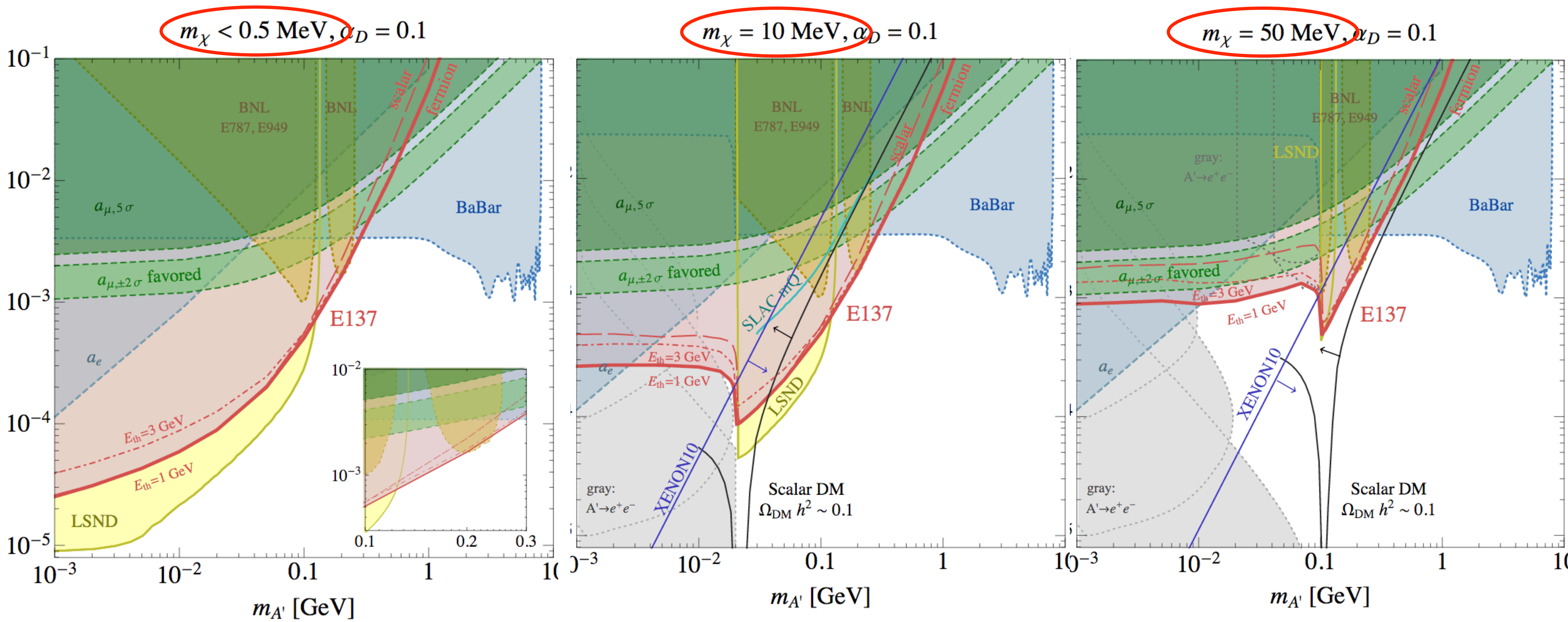
DM searches: re-analysis of E137@SLAC

Limit depends on M_χ and α_D

region $M_{A'} < 2\,M_\varphi$, virtual transition → acceptance drop → worse sensitivity

Similar analysis for LSND (Large Scintillator Neutrino Detector) data interpreted as:

10^{23} 800-MeV POT, $p\,N \to \pi^0 X$, $\pi^0 \to \gamma A'$, $A' \to \varphi\varphi^*$, valid if $M_\varphi < M_{\pi^0}/2$

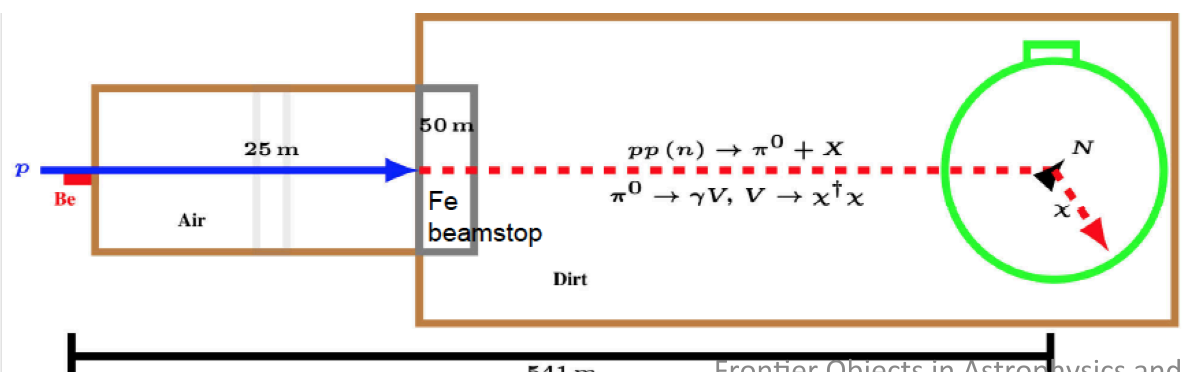


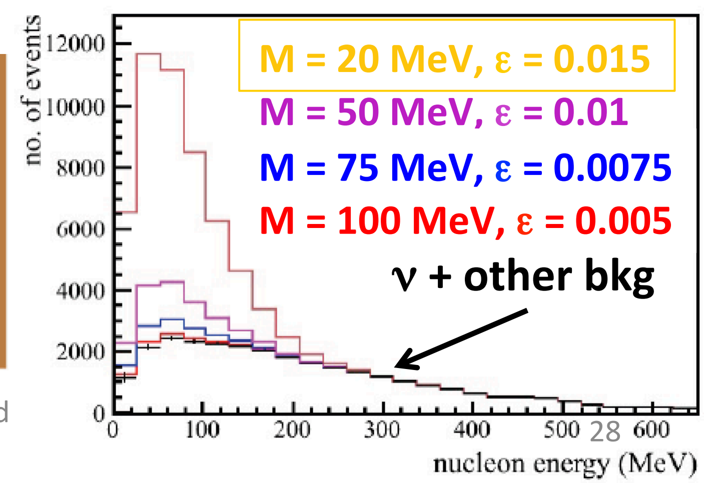
Neutrino experiments turned to DM

MiniBoone @ FNAL booster (2002-2012), ν_e appearance and ν interactions
Search for DM-nucleon scattering, dedicated run ~1.9 10^{20} POT in 2014 (10 months):
  DM alters NC elastic yield vs nucleon kinetic energy wtr for ν's
  move beam off-target to Fe dump, reduce ν rate by x50
  signal: ~100-MeV recoil pt from scintillation light (800 ton mineral oil, 1280 8" PMT's)

Analysis in progress, expect to improve from 50 MeV to 1 GeV [10% systematic error]

Future experiment might exploit:
  TOF (for high DM masses)
  Energy cuts (if off-axis detector, expect DM spectrum softer than for ν)
  Scattering-angle cuts: ask forward for DM-e^- scattering





Neutrino experiments to detect DM

Existing facilities

LSND, 10^{23} 800-MeV POT, off-axis detector @ 30 m (like a beam dump)

Short Baseline (SBND) @ FNAL, 2 10^{20} 9-GeV POT, 260 ton LAr TPC @ 110 m from target
expect to improve on MiniBoone by ~10—20

T2K, 10^{21} 30-GeV POT, 2^o off-axis detectors: near (2 ton, 280 m) and far (~50 kton, SuperK)

Future facilities

COHERENT @ SNS, 10^{23} 1-GeV POT/yr, 90^o off-axis at 20m
SHiP, 5 10^{19} 400-GeV POT/yr, ~10 ton LAr-TPC on-axis at ~100m
MicroBooNE & NOvA

LBNF/DUNE @ FNAL, 3 10^{21} 120-GeV POT/yr, near detector 3.5 m radius at ~ 500 m
optimization for DM under study:
either DM detector off-axis (> 2^o) or DM detector after dump + horns&dipole for ν's

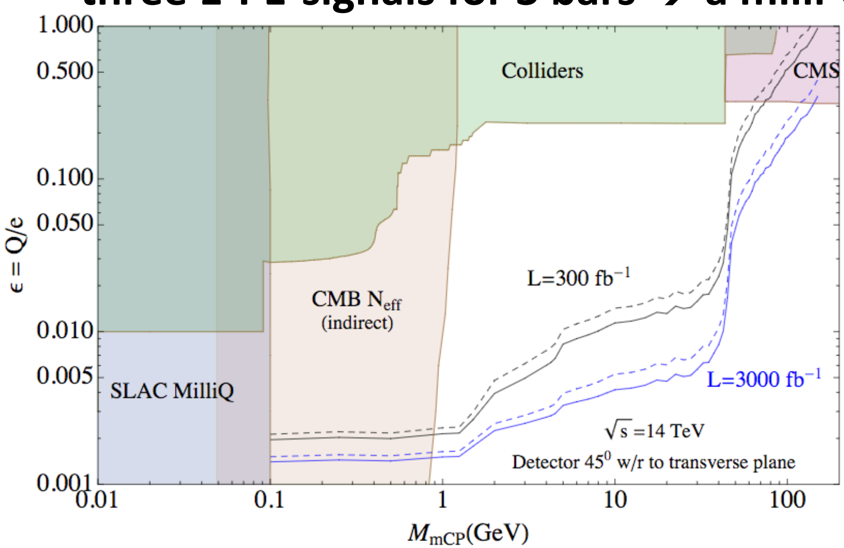
Exotic A' fenomenology: millicharges

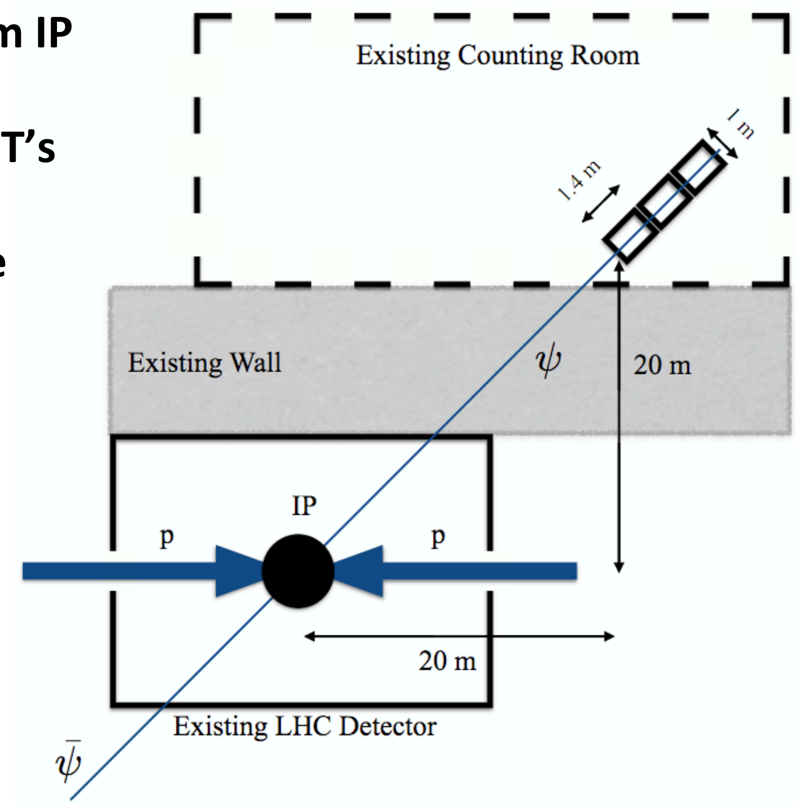
Massless A' mix with ordinary γ → DM coupled to our hypercharge has a "milli-charge" εe

Unsuccessfully searched for at the SLAC MilliQ experiment
Signature proposed for LHC [Haas et al., arXiv:1410.6816v2]: Drell-Yan pp→ψψ*X

Detect millicharged particles using high-yield scintillator bars in a shielded environment
Instrument 1 m³ of plastic scintillator at 20 m from IP (e.g. USA15@ATLAS)

- **3 sets of 1.4-m long scintillator bars with PMT's**
- **1 MIP ~ 10^6 PE's**
- **three 1-PE-signals for 3 bars → a milli-charge**





Briefly about other “portals”: HNL

NP with 3 singlet fermions (heavy neutral leptons, HNL) might explain [Shaposhnikov et al.]:

neutrino masses
dark matter density
baryon asymmetry of the universe

Observation:

standard “see-saw” means a Gut-scale Majorana mass with O(1) Yukawa
OK, you can obtain the same with very small Yukawa’s, such as those for a DM particle

Phenomenology of heavy neutrinos:

modified kinematics π, K, $D_{(s)} \rightarrow \mu(e)N$, K ->$\pi$lN, etc.
semileptonic decays, $N \rightarrow \pi\mu$, πe, etc.

Visible/invisible searches as A’

K, D production
prompt decays/beam dump

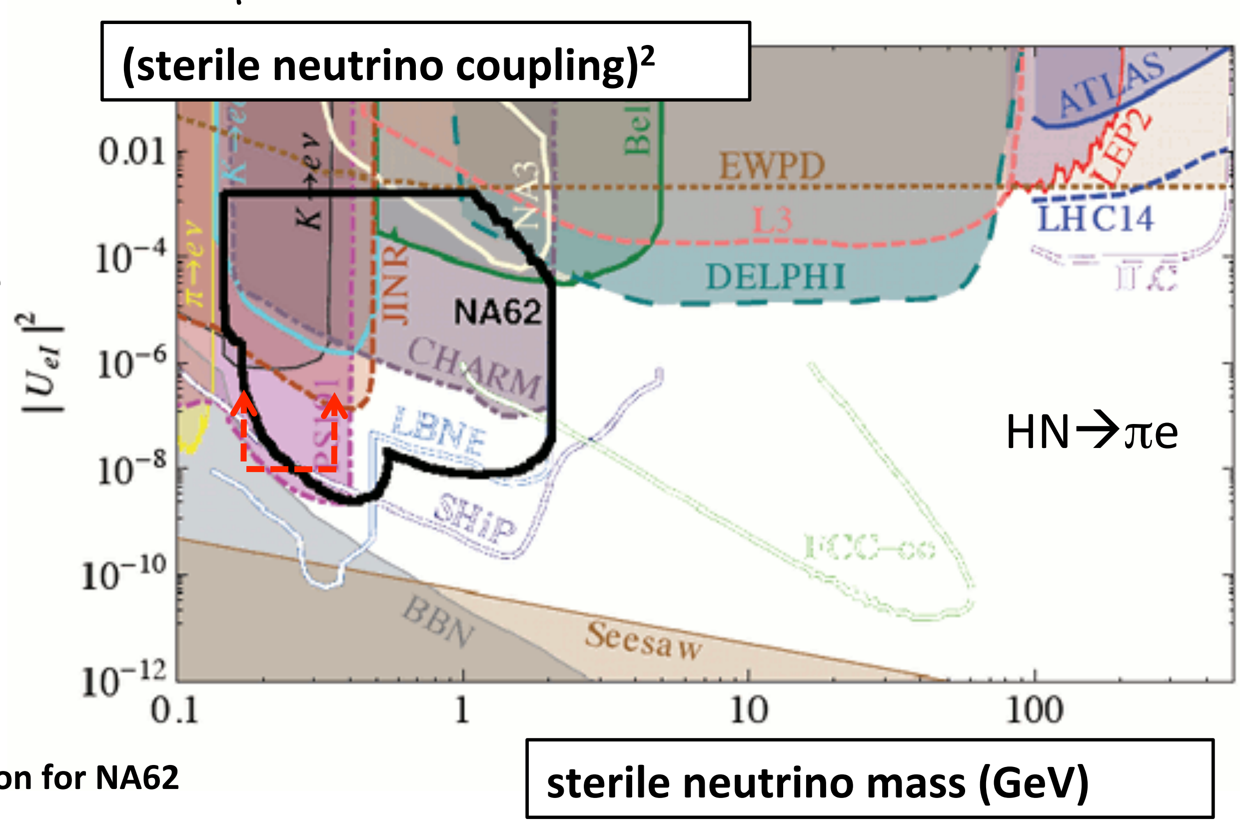
Briefly about other “portals”: HNL

Mesons ($D_{(s)}$, K’s) produced at target might decay to long-lived exotic particles reaching the NA62 decay volume

The simplest signatures for heavy neutral leptons correspond to two-body (semi)leptonic decays: HN→πe, πμ

Production + decay: yield ~ (coupling)^4

Complementary to the invisible search from Ke2 decays using 2015 data from NA62 (expectation, which should exceed limit from 0νββ decays)



arXiv:1504.04855 + **my evaluation for NA62**

Briefly about other “portals”: ALP’s

Motivation in strong CP QCD problem [Quinn, Peccei]: Axions

ALP: anything light and (pseudo-)scalar coupled to SM particles by dimension-5 [Beyond the strong CP]

Coupling to photons: $$\mathcal{L} = \frac{1}{2}\partial^\mu a\, \partial_\mu a - \frac{1}{2} m_a^2\, a^2 - \frac{1}{4}\, g_{a\gamma}\, a\, F^{\mu\nu} \tilde{F}_{\mu\nu}\ ,$$

Phenomenology:

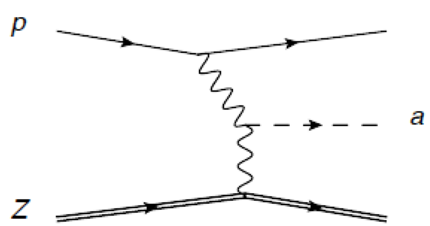
- **Low mass, production/detection mediated by strong-em field**
- **High mass, production via Primakoff/detection from its $\gamma\gamma$ decay**

Briefly about other “portals”: ALP’s

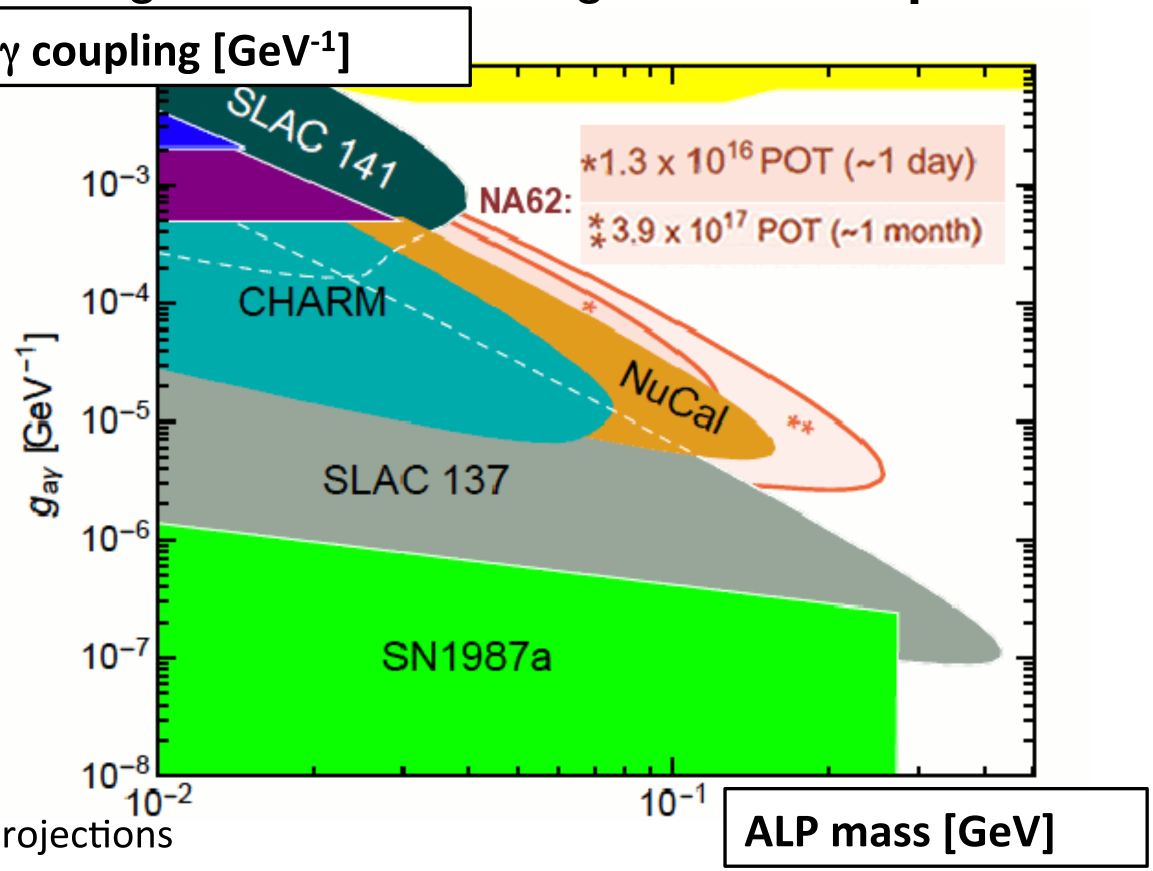
Search for light (pseudo-)scalar particles coupled to two gauge bosons (here, SM photons) produced at target and decaying to $\gamma^{(*)}\gamma^{(*)}$ in the NA62 fiducial volume

Difficult search to be performed during standard data taking: **beam-dump mode**

Production mechanism studied: Primakoff production



Expected zero-background sensitivity for 1 day (*) and 1 month (**) runs in beam dump mode improves on present results



JHEP 1602 (2016) 018 + includes NA62 projections

Present/future of MeV-GeV DM: a very vibrant field

Vector portal: visible search

Name	Where	Source	Intensity	Production mode	Detection mode	Status
Belle-II	Super KEK-B	$e^+e^- \to \Upsilon(3S)$	> 100 fb^{-1} @ $\Upsilon(3S)$	$\Upsilon(3S) \to \gamma A'$	$A' \to e^+e^-, \mu^+\mu^-$	Commis. 2018
Apex	JLAB	e^-, 2 GeV	10^9 EOT (W)	A'-strahlung	$A' \to e^+e^-$	Commis. 2018
HPS	CEBAF12 @ JLAB	e^-,1-2 GeV	10^{14} EOT (W)	A'-strahlung	$A' \to e^+e$,	Running 2016-20
MAGIX	MESA @ Mainz	e^-, 155 MeV	10^{16} EOT (Xe gas)	A'-strahlung	$A' \to e^+e$,	Commis. 2020
Mu3e	πE5 line @ PSI	μ^-, 28 MeV	10^{15-16} μ^-	$\mu \to \nu\nu A'$	$A' \to e^+e^-$	Commis. 2017
ATLAS/CMS	LHC @CERN	pp 8, 13 TeV	few fb^{-1}	$H \to 4l$ + MET	$A' \to \mu^+\mu^-$	Running
LHCb	LHC @CERN	pp,13 TeV	15 fb^{-1}	$D^* \to DA'$	$A' \to e^+e^-, \mu^+\mu^-$	Running
NA62	SPS @CERN	p, 400 GeV	2 10^{18} POT	Meson, A'-strahlung	$A' \to e^+e^-, \mu^+\mu^-$	Running –2018
SeaQuest	Main Inj. @ FNAL	p, 120 TeV	1.5	Meson, A'-strahlung	$A' \to \mu^+\mu^-$	Proposed 2017–19
SHiP	SPS @CERN	p, 400 GeV	2 10^{20} POT	Meson, A'-strahlung	$A' \to e^+e^-, \mu^+\mu^-$	Proposed 2026

Vector portal: invisible search

Babar	PEP-II @ SLAC	$e^+e^- \to \Upsilon(3S)$	57 fb^{-1}	$\Upsilon(3S) \to \gamma A'$	Single-γ trigger	ICHEP 2016
VEPP-3	VEPP-3 @ Budker Inst.	e^+, 500 MeV	1.5 MHz $\gamma\gamma$	$e^+e^- \to A'\gamma$	detect γ + $M_{\rm miss}$	Proposed
PADME	BTF @ Frascati INFN	e^+, 550 MeV	15 Hz $\gamma\gamma$	$e^+e^- \to A'\gamma$	detect γ + $M_{\rm miss}$	Approved, 2017-19
MMAPS	CESR @ Cornell	e^+, 5.3 GeV	2.2 MHz $\gamma\gamma$	$e^+e^- \to A'\gamma$	detect γ + $M_{\rm miss}$	Not funded
NA64	SPS @ CERN	e^-, 100 GeV	$e^-N \to e^-NA'$	10^9–10^{12} EOT	detect e^- + $E_{\rm miss}$	Running, 2016-17
LDMX	LCLS-II @ SLAC	e^-, 4 GeV	$e^-N \to e^-NA'$	10^{15}–10^{16} EOT	detect e^- + $E_{\rm miss}$	Proposed, 2020

Vector portal: DM search

SBND	FNAL	p, 9 GeV	2 10^{20} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 110 m	Under study
T2K	Tokai-Kamioka	p, 30 GeV	10^{21} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 280 m	Running
COHERENT	SNS @ Oak Ridge	p, 1 GeV	10^{23} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 20 m 2^o-OA	Proposed
SHiP	SPS @CERN	p, 400 GeV	2 10^{20} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 100 m	Proposed 2026
LBNF	DUNE @FNAL	p, 120 GeV	3 10^{21} POT	Meson, A'-strahlung $A' \to \varphi\varphi$	detect ϕ @ 500 m	Under study 2020

Some of the above will address neutrino portal, too: neutrino experiments, NA62, SHiP
Some of the above will address ALP portal, too: NA62, SHiP

Conclusions

A motivated experimental effort ongoing to pin down DM candidates in laboratory

Ultra low- and high-mass direct DM searches: no clear indication of DM mass and model

Searches in the MeV-GeV mass range suggested by different sources

Present and planned experiments span different techniques:

high-energy colliders
high-intensity proton, electron, and positron beams
low-energy, high-luminosity colliders
short- and long-baseline neutrino experiment

Different candidates and DM scenarios simultaneously under test

Present status:

- **Re-analyses of past fixed-targed and neutrino experiments**
- **No clear DM signal in the lab from running experiments**
- **A number of new proposals for near future**