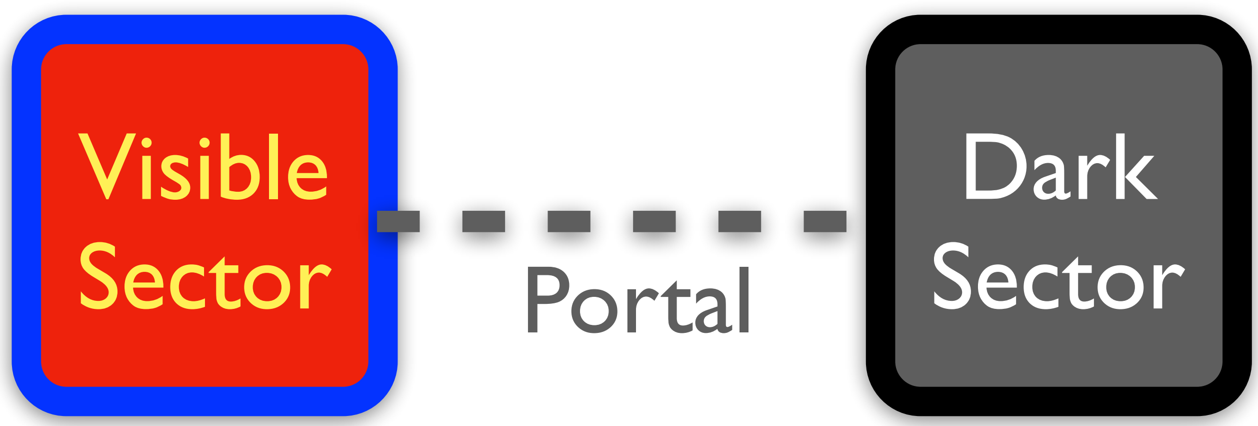
RF6 Dark Sectors at High Intensities

Theory Introduction



Brian Batell (Pitt) and Philip Schuster (SLAC)

Snowmass RF6 Kickoff Meeting
August 12-13, 2020

see overview talk by S. Gori

What is a Dark Sector?

- Set of new particles which do not experience the known forces.
- Weakly coupled to visible sector through a mediator or "portal".

Why Dark Sectors?

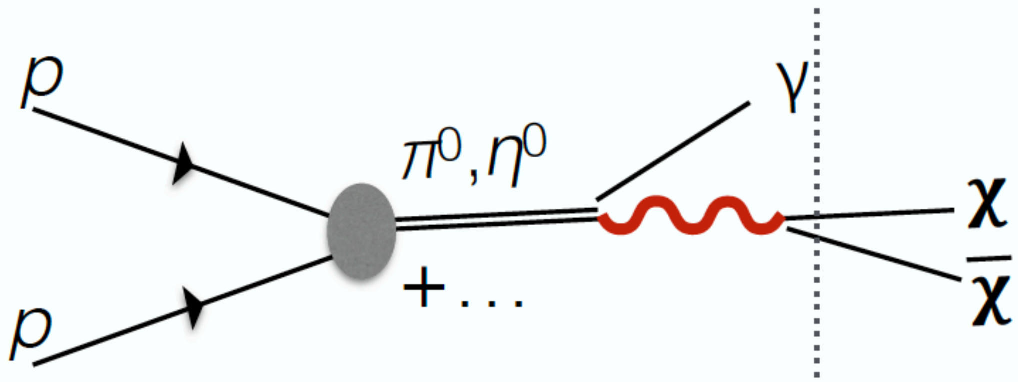
- Dark matter may reside in the dark sector. Simple (thermal) and novel cosmologies are possible.
- Dark sectors may play a role in addressing other puzzles, e.g., neutrino masses, matter-antimatter asymmetry, naturalness, …
- Experimental anomalies often interpreted in context of dark sectors.

Why high intensities?

- High intensities allow probes of weak portal couplings.
- Past/existing high intensity experiments already provide leading constraints.
- Great potential to discover dark sectors and discern their structure with new searches and experiments in the coming years.

Benchmark studies

- One natural way to organize benchmarks is according to final state signatures
- This scheme aligns well with the science case



"Once you get in to the dark sector, what do you look for?"

non-SM	SM	mixed
Dark Matter Production	**Portal-Mediator Decays to SM**	**Structure of the Dark Sector**
Producing stable particles that could be (all or part of) the Dark Matter	Systematically explore the minimal couplings of SM to dark sectors	There could be a rich sector of new physics under our noses

from talk by N. Toro, Dark Sectors and Light Long-Lived Particles cross frontier meeting

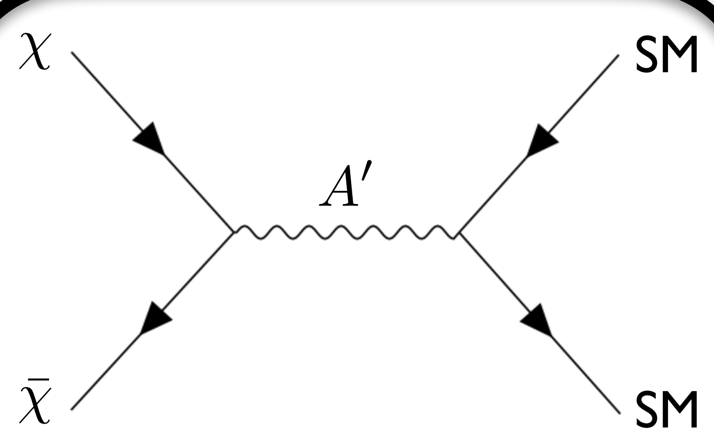
https://indico.fnal.gov/event/44030/

Dark matter production at high intensities

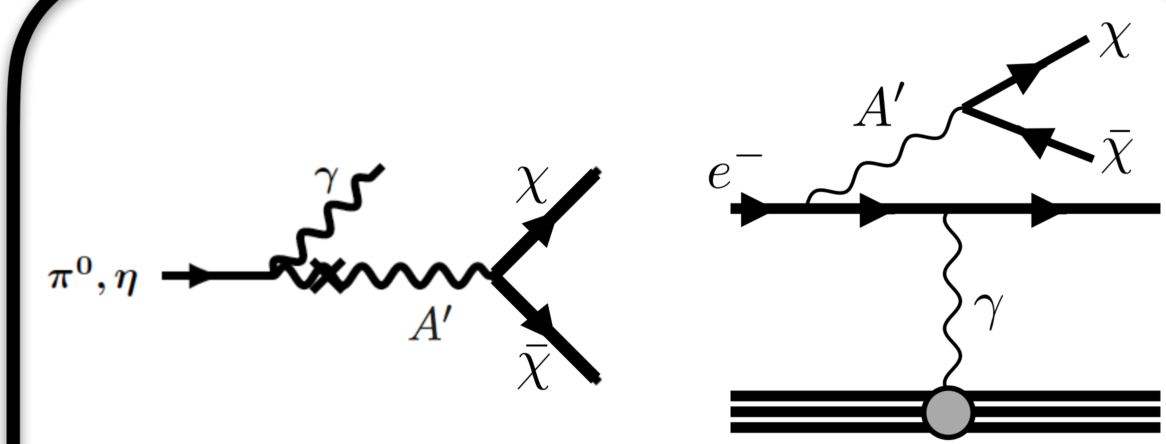
see talk by G. Krnjaic

- Cosmological DM abundance generated via thermal freeze-out
- Extension of the WIMP below Lee-Weinberg bound

- Direct DM annihilation to SM leads to predictive targets for experiment
- Same interaction governs DM annihilation and laboratory DM production



DM annihilation in the early universe



DM production in the laboratory

Portal/mediator production/decay at high intensities

see talk by A. Ritz

- The mediator (or "portal") plays critical role in dark sector physics
  - Renormalizable portals:

$\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$	Vector Portal
$(A\,S + \lambda\,S^2)\,H^\dagger H$	Higgs Portal
$y N L H$	Neutrino portal

  - Other possibilities include higher dimension operators (e.g., axion portal), gauging conserved currents ($B-L$, $L_\mu - L_\tau$, $\ldots$), etc.
- The mediator can decay back to visible SM final states through the same portal coupling (can be prompt or displaced/long-lived)
- Dark matter can still be thermally produced through "secluded" annihilation to mediators
- Typically very simple parameter space (mass — coupling plane)

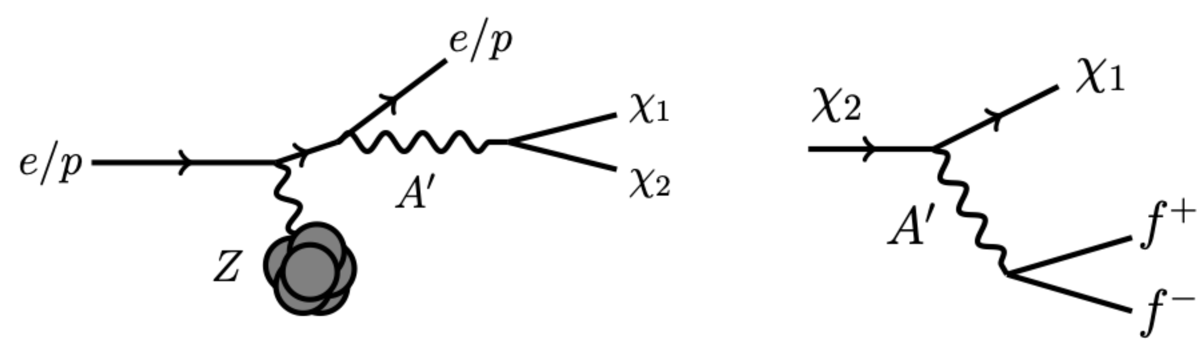
Rich dark sectors at high intensities

see talk by A. Berlin

- The dark sector may be as rich as the Standard Model. It could feature may feature myriad novel phenomena such as spontaneous symmetry breaking, confinement, supersymmetry, …
- UV considerations may call for additional structure (e.g., a dark Higgs generates dark photon mass, which may further cause DM mass splittings)
- Novel DM cosmology may suggest rich structure as in e.g., SIMP
- Rich dark sector structure often leads to novel experimental signatures

e.g., inelastic DM

from 1703.06881



- Much work remains to characterize and fully explore rich dark sectors

Benchmarks in Final State x Portal Organization

	DM Production	Mediator Decay Via Portal	Structure of Dark Sector
Vector	*m_χ vs. y [$m_{A'}/m_\chi$=3,α_D=.5]* **$m_{A'}$ vs. y** [α_D=0.5, 3 m_χ values] m_χ vs. α_D [$m_{A'}/m_\chi$=3, y=y_{fo}] m_χ vs. m_A [α_D=0.5, y=y_{fo}] ***Millicharge m vs. q***	$m_{A'}$ vs. ϵ [decay-mode agnostic] ***$m_{A'}$ vs. ϵ [decays]***	**iDM m_χ vs. y [$m_{A'}/m_\chi$=3,α_D=.5] (anom connection)** **SIMP-motivated cascades [slices TBD]** $U(1)_{B-L\,/\,\mu-\tau\,/\,B-3\tau}$ (DM or SM decays)
Scalar	m_χ vs. $\sin\theta$ [λ=0, fix m_S/m_χ, g_D] (thermal target excluded 1512.04119, should still include) Note secluded DM relevance of S→SM of mediator searches	*m_S vs. $\sin\theta$* [λ=0] *m_S vs. $\sin\theta$* [λ=s.t. Br(H→$\phi\phi$ ~10^{-2})]?	Dark Higgssstrahlung (w/vector) scalar SIMP models? Leptophilic/leptophobic dark Higgs?
Neutrino	e/μ/τ a la1709.07001?	*m_N vs. U_e* *m_N vs. U_μ* *m_N vs. U_τ* Think more about reasoanble flavor structures	Sterile neutrinos with new forces?
ALP	m_χ vs. fq/l [λ=0, fix m_a/m_χ, g_D] (thermal target excluded) What about f_γ, f_G?	*m_a vs. f_γ* *m_a vs. f_G* *m_a vs. f_q=f_l* (separate?) Think more about reasoanble coupling relations including $f_{W/Z}$	FV axion couplings

+ Neutron portal? Hidden valleys (or are these out-of-scope?)? See e.g. 2003.02270

Bold = BRN benchmark, *italic=PBC benchmark.* others are new suggestions. Underline=CV benchmarks that were not used in BRN

Resources

- Dark Sectors 2016 Workshop: Community Report

  https://arxiv.org/abs/1608.08632

- U.S. Cosmic Visions: New Ideas in Dark Matter 2017: Community Report

  https://arxiv.org/abs/1707.04591

- Physics Beyond Colliders at CERN: Beyond the Standard Model Working Group Report

  https://arxiv.org/abs/1901.09966

- Basic Research Needs for Dark Matter Small Projects New Initiatives

  https://science.osti.gov/-/media/hep/pdf/Reports/Dark_Matter_New_Initiatives_rpt.pdf