

# **Big Ideas 3 :**

## **New flavors and rich structures in dark sectors**

P. Harris(MIT), P. Schuster(SLAC), J. Zupan (Cincinnati)

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**May 18th, 2022**

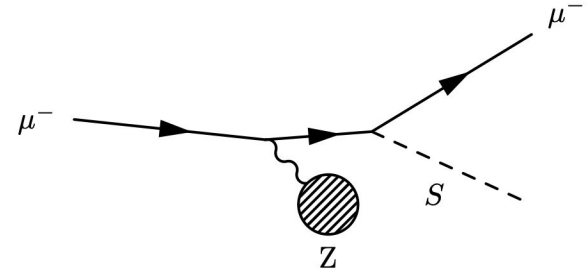
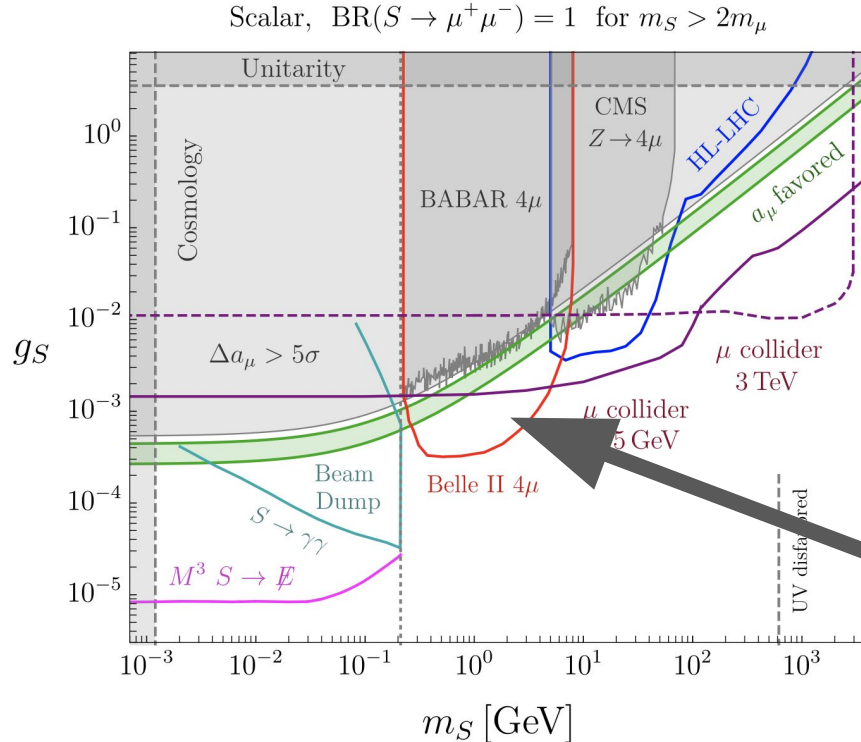
# Logistics

- Current draft of the paper is located here :  
[https://www.dropbox.com/s/w18ixeztbp07h7x/Snowmass\\_RF6\\_Big\\_Idea\\_3.pdf?dl=0](https://www.dropbox.com/s/w18ixeztbp07h7x/Snowmass_RF6_Big_Idea_3.pdf?dl=0)
- Please send any comments to :
  - [pcharris@mit.edu](mailto:pcharris@mit.edu) [schuster@slac.stanford.edu](mailto:schuster@slac.stanford.edu) [zupanje@ucmail.uc.edu](mailto:zupanje@ucmail.uc.edu)
- In the next set of slides we will review the paper draft
  -
- This meeting we would like to finalize any missing scope
  - Ensure that we have coverage of the critical ideas
  - Please speak up in this meeting if we are missing a something

# Strategy

- Aimed to cover 3 major motivations for extended dark sectors
  - Data based anomalies
  - Simple Motivated extensions
  - Theoretical motivations
- Picked a few examples that highlight these
  - No intention of being exclusive
  - Critical point is what we chose to highlight
- We should aim to harmonize plotting styles across papers
  - Not clear which main plots should come from BI3

# Data Motivated Anomalies $\Rightarrow (g-2)_\mu$



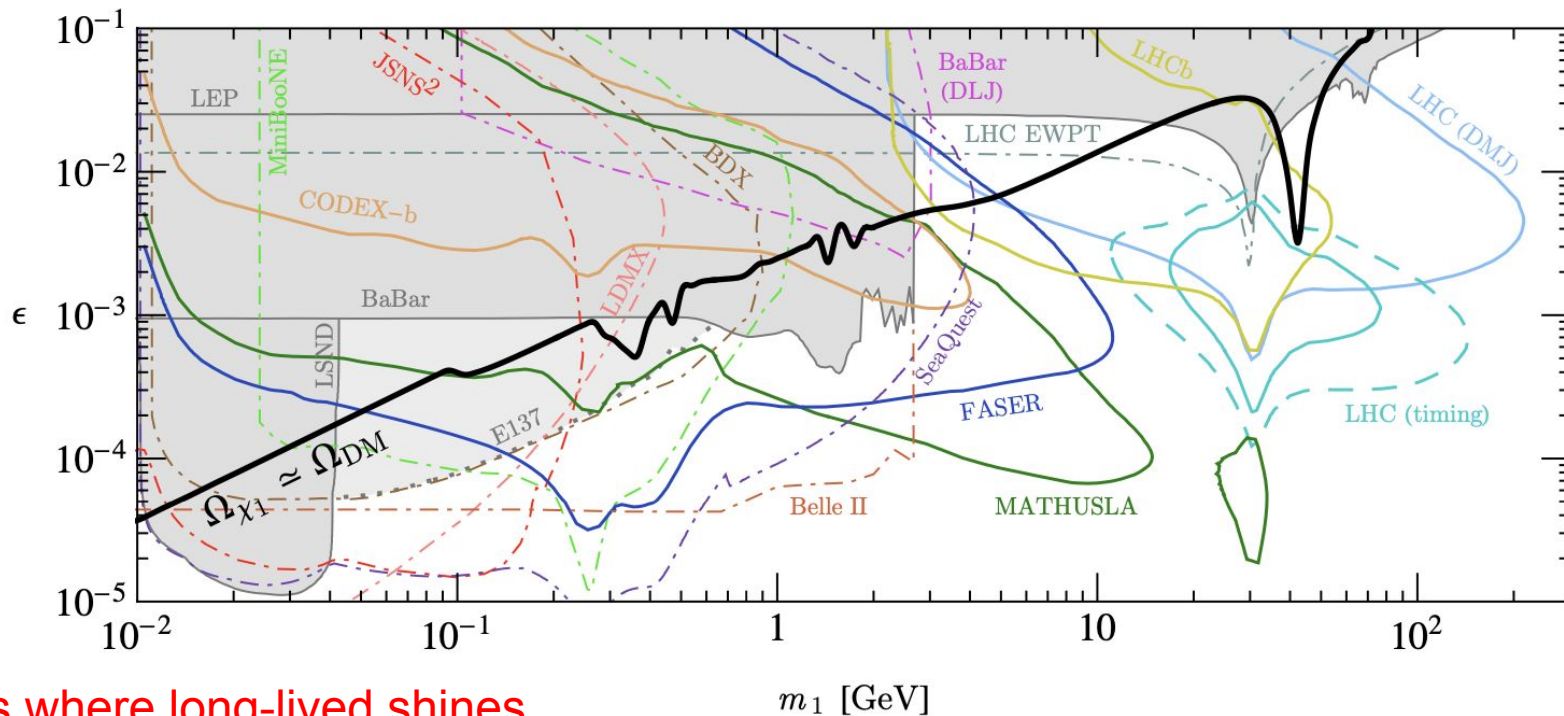
General Message, this is where Muon beams shine

$(L_\mu - L_\tau)$  in extended

Secondary Muons from proton beam dumps to appear here too

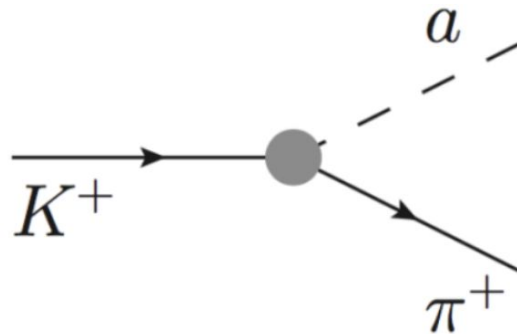
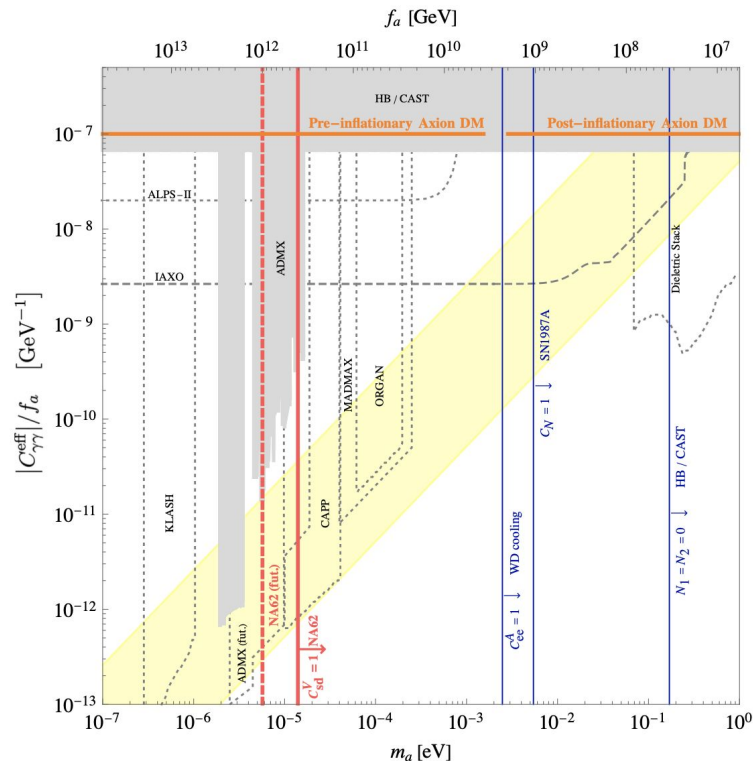
# Simple extensions of the standard model

Fermionic iDM,  $m_{A'} = 3m_1$ ,  $\Delta=0.1$ ,  $\alpha_D=0.1$



This is where long-lived shines

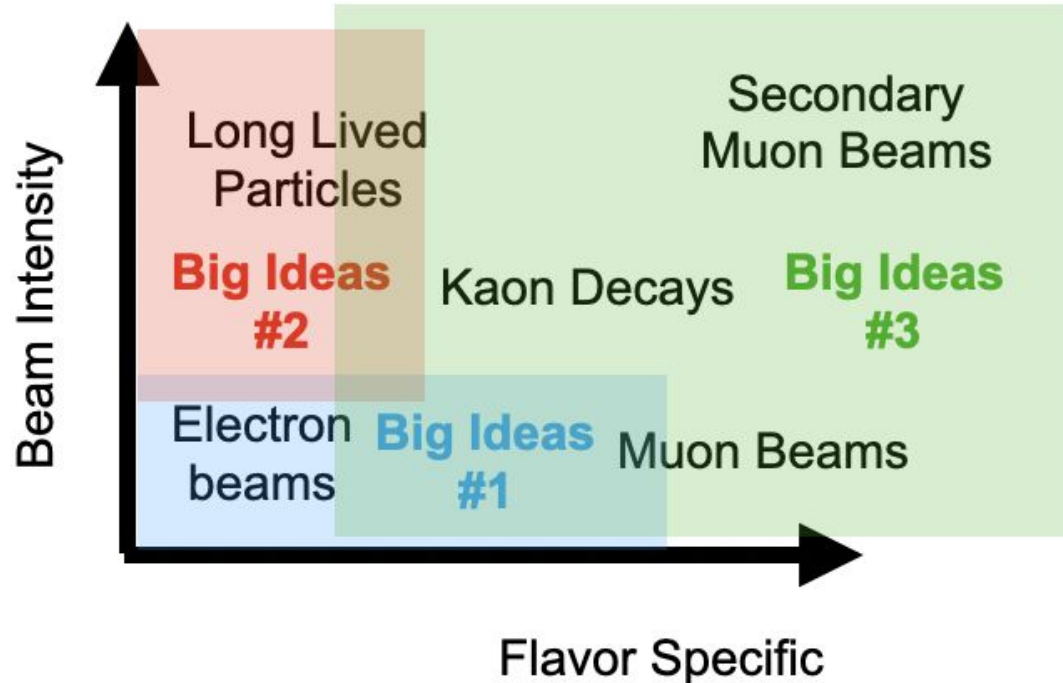
# Theoretical Motivations



Connecting Kaon decays with  
the standard Model Axion

(Not really like the other plots)  
Missing a huge number of lines

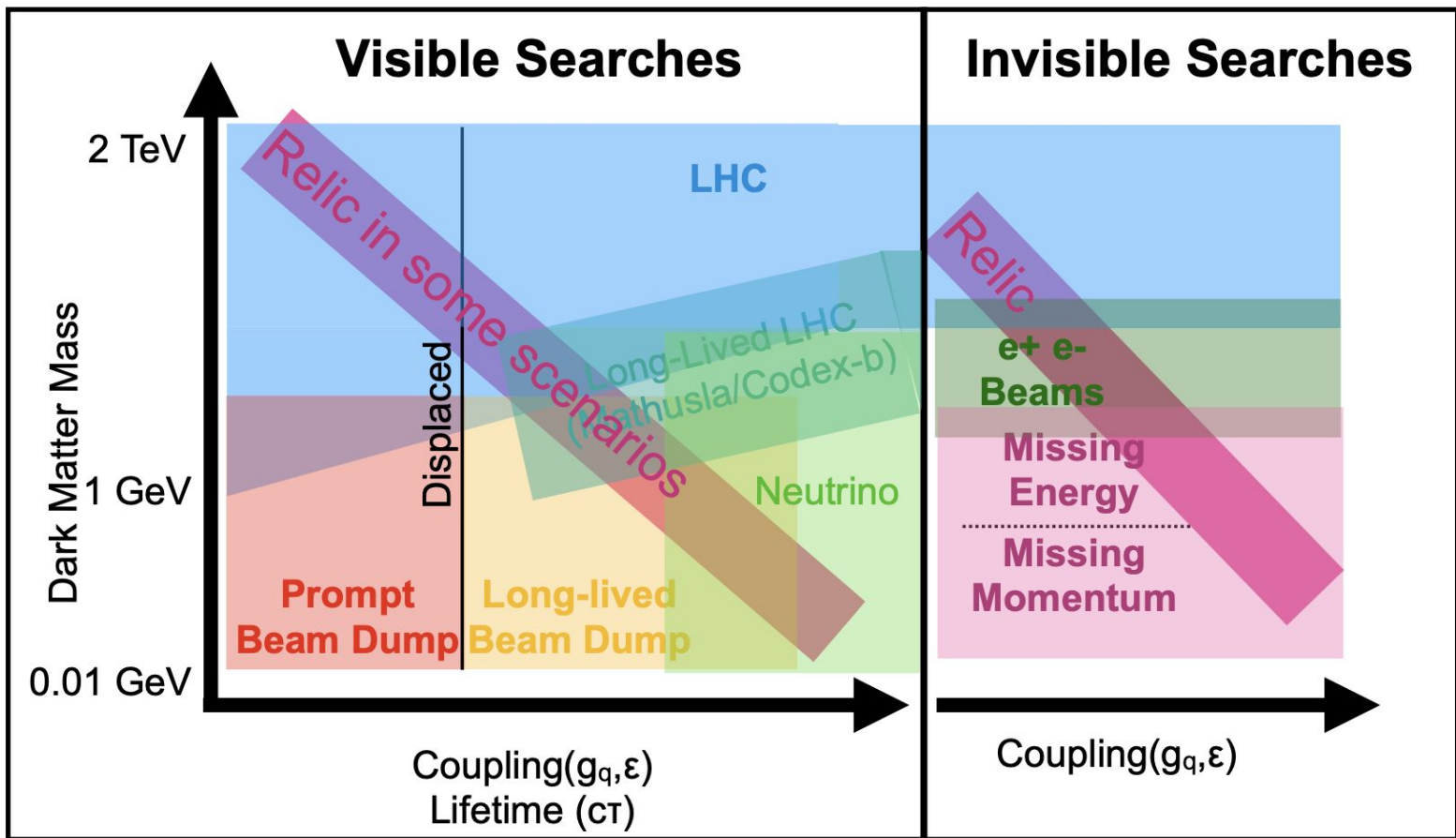
# Experimental Front



# What needs to be done

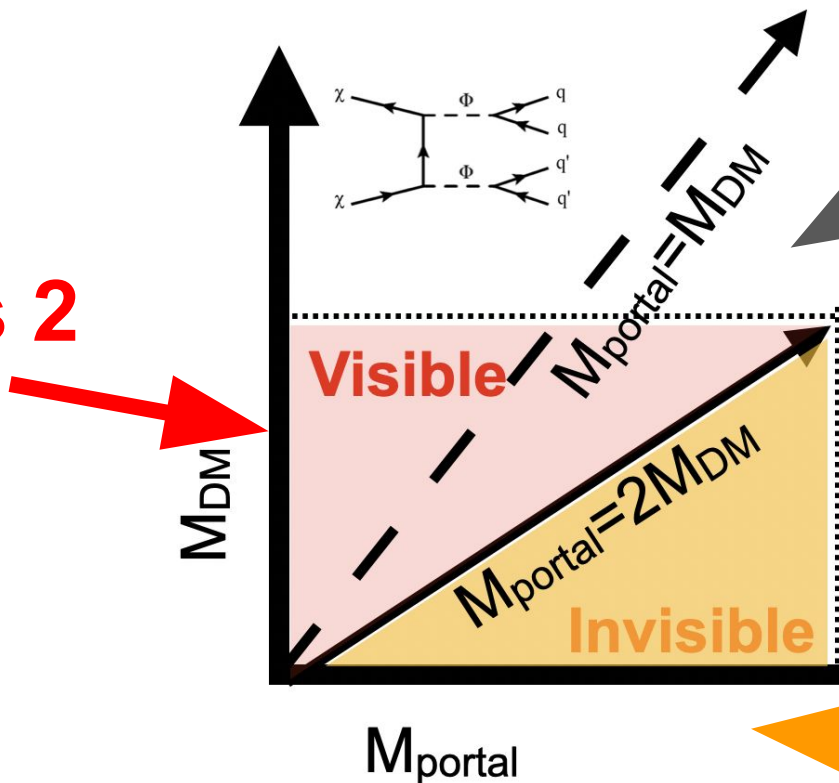
- Add Mike's messaging suggestions:
  - exploiting capabilities of existing large multi-purpose detectors + near-future upgrades;
  - Investing in specialized small-scale experiments + Investing in facilities that can deliver high-intensity beams;
  - Supporting the theory community to further develop theory of dark sector
- Additional Suggestions from Stefania
  - Is there a way to highlight more BSM physics?
  - Highlight secondary muon beams
- It would be good to harmonize the plot structure of critical plots

# More Details

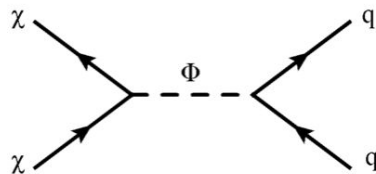


# Framing Big Idea 3

**Big Ideas 2**



Region where  
relic yields  
Some constraints

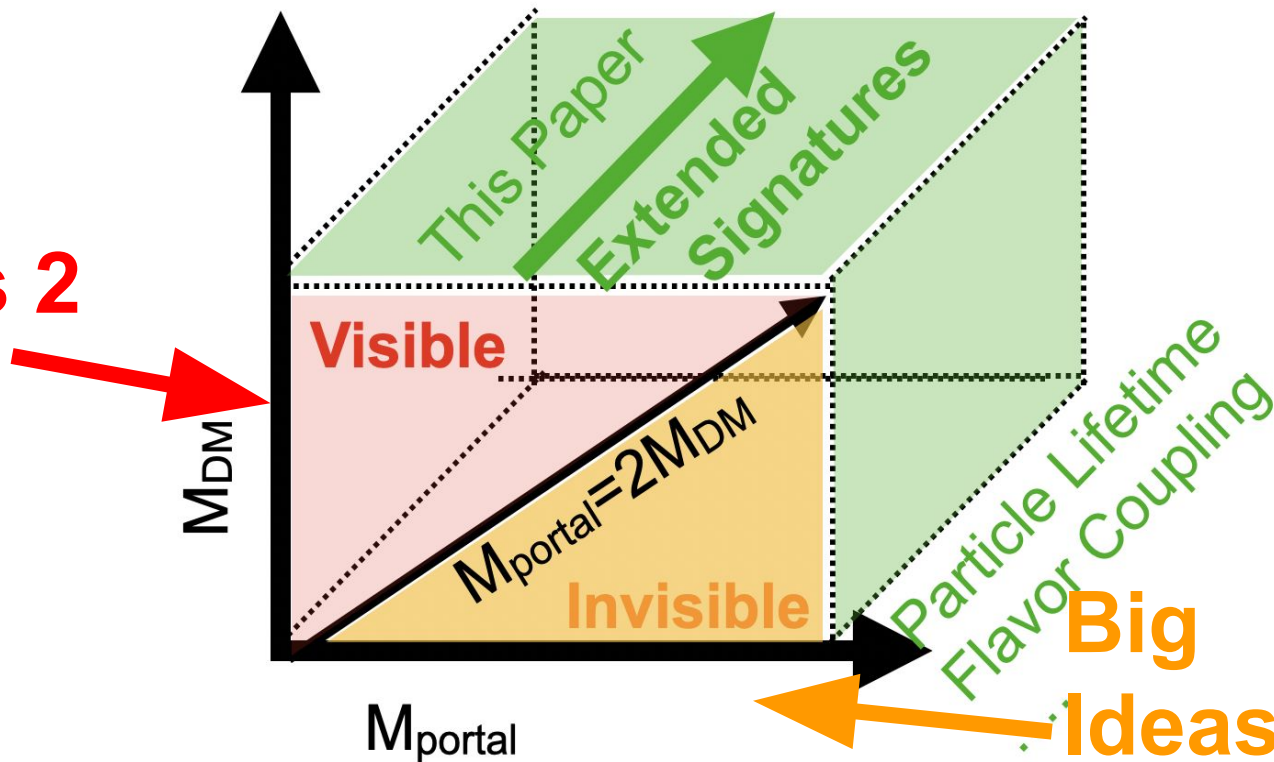


**Big Ideas 1**

# Framing Big Idea 3

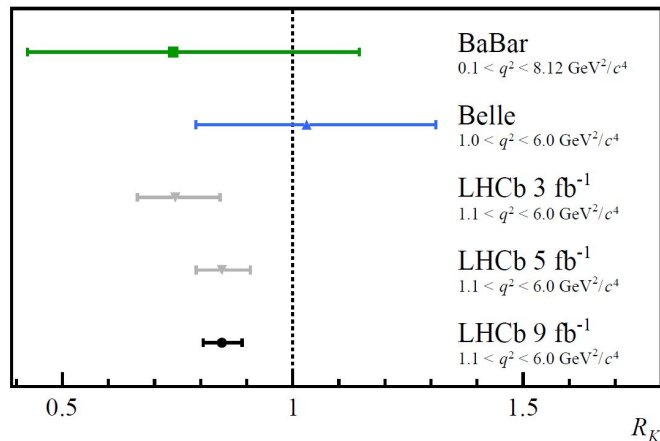
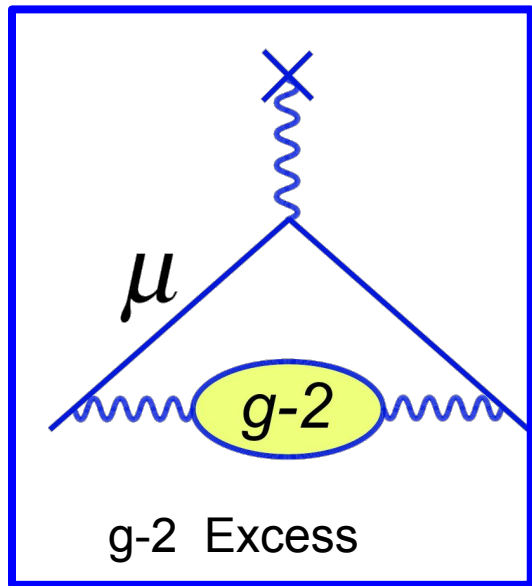
Big Ideas 3

Big Ideas 2

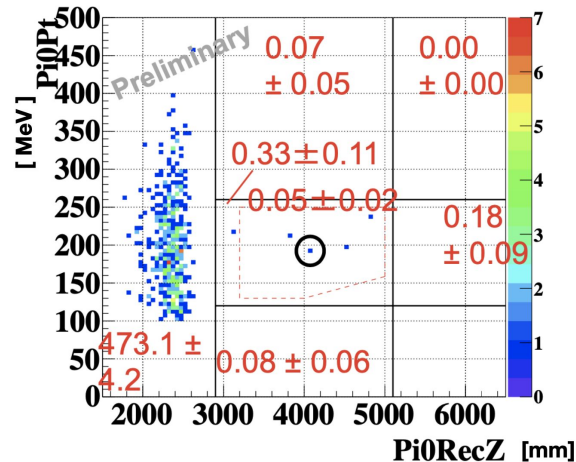


Big Ideas 1

# Big Idea 3: Data-driven Motivations



B-physics anomalies



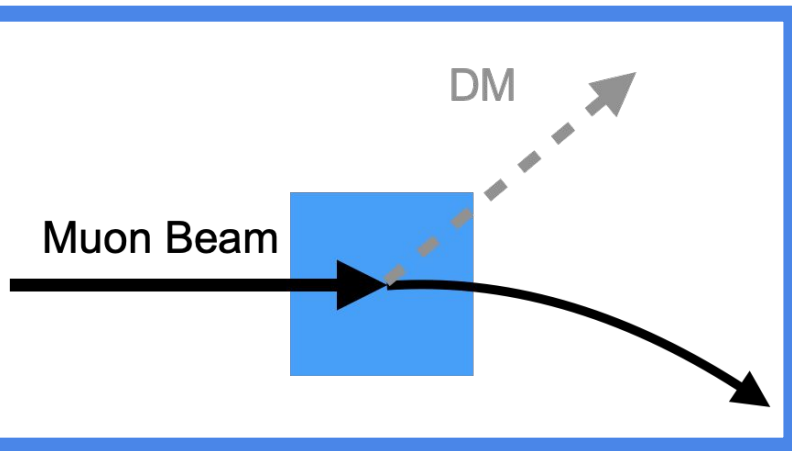
KOTO excess ....

Our Anomaly of choice!

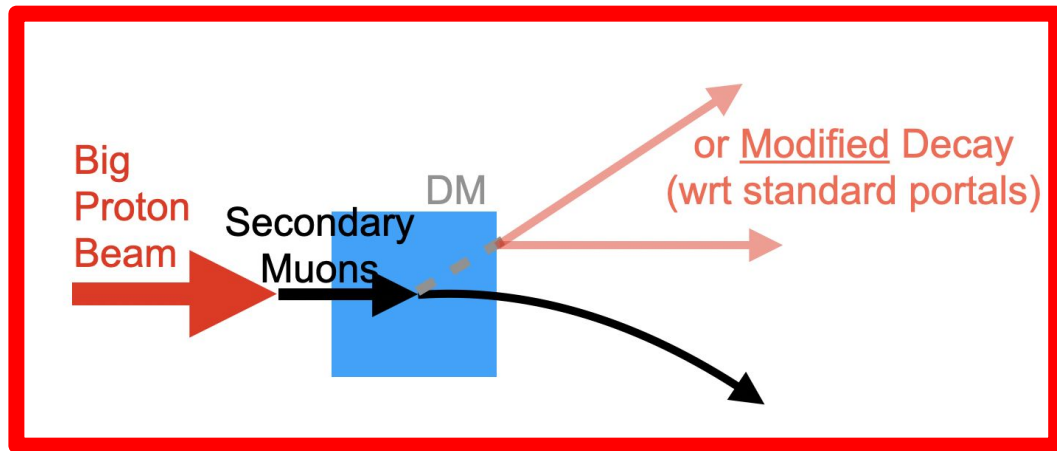
## Recent list of many anomalies

# How do you explain $g-2_\mu$ excess?

- Safest way to probe  $g-2_\mu$  excess is with muons
- 3 Good sources of muons
  - Muon beams, secondary muons, or intense  $e^+e^-$  collider(Belle)



Muon+Missing Energy

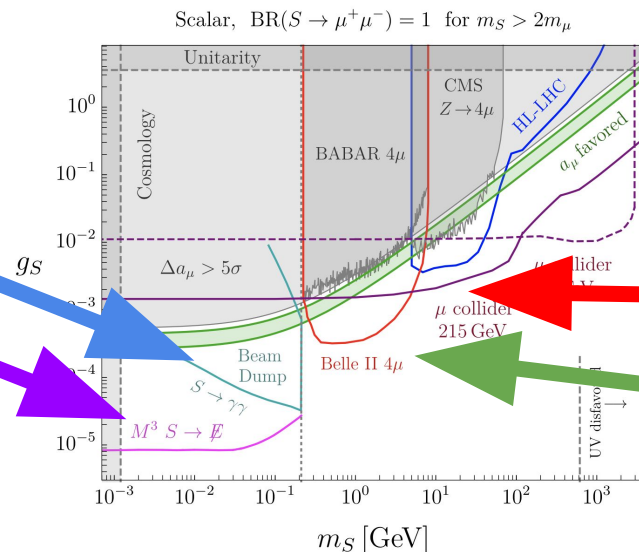


Beam Dumps and the like

# How do you explain g-2 excess?

- In minimal scenario consider just a muon coupling
  - Can explain this through a scalar coupling

other Muon  
beams  
 $M^3$  experiment



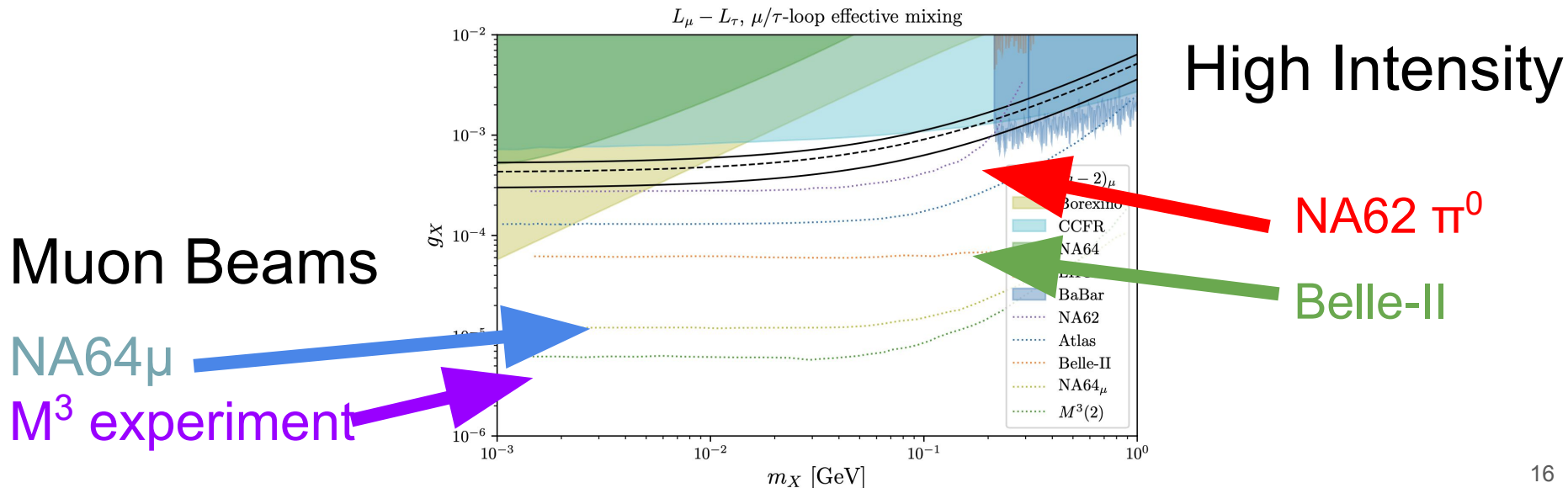
High Intensity

Belle-II  $4\mu$

Secondary Muons  
From proton beams  
(Not yet shown)

# How do you explain g-2 excess?

- With a more complicated scenario
  - Can consider an explanation with  $L_\mu$ - $L_\tau$

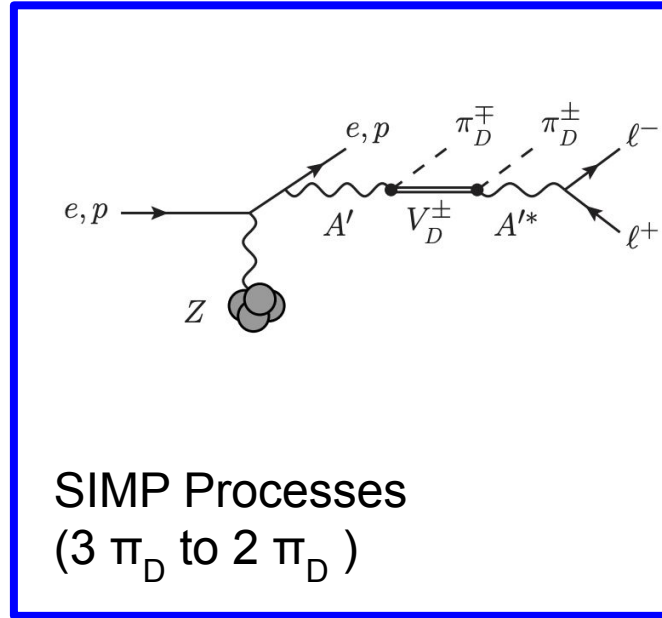
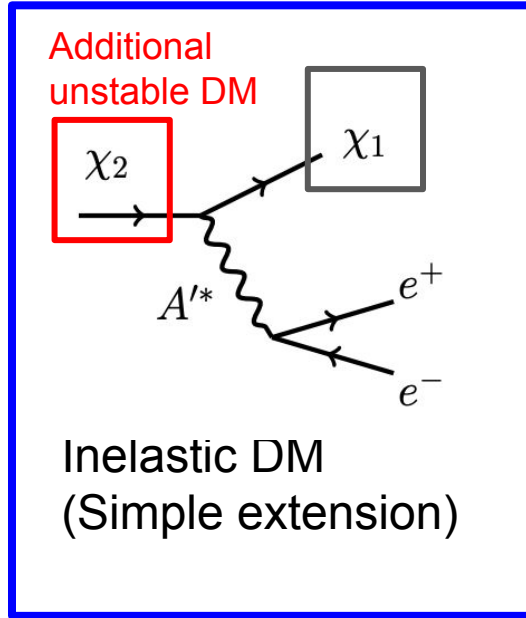


# Other anomalies that we touched on

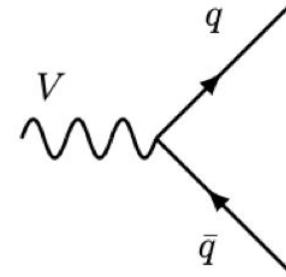
- $(g-2)_\mu$
- B Physics anomalies
  - RK and other flavor anomalies
- Xenon 1T
- MiniBoone Excess
- Beryllium
- Neutron lifetime anomaly
- KOTO

Discussion: Have we missed one? (W mass?)

# Big Idea 3: Simple Theory Extensions



$V \rightarrow \text{hadrons}$



Hadrophilic DM  
To avoid existing bounds

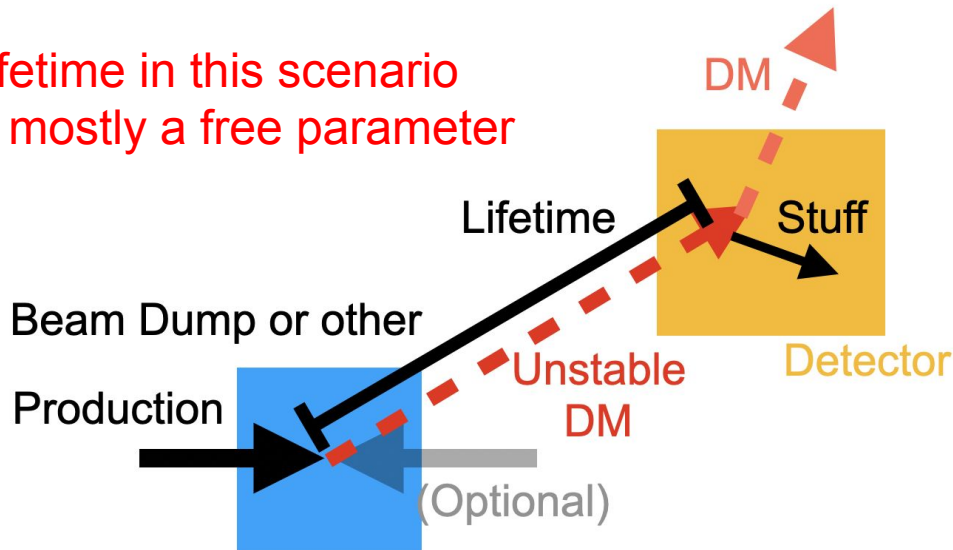
We highlight two models

Strategy is to consider simple well motivated models

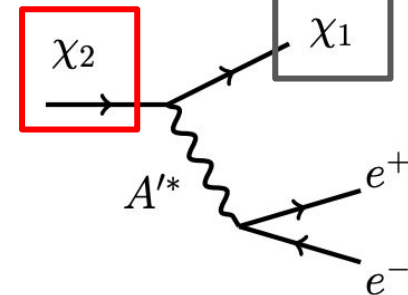
# Inelastic DM: Example of a minimal extension

- Start with the usual portal
  - Add an unstable DM candidate

Lifetime in this scenario  
Is mostly a free parameter



Additional  
unstable DM

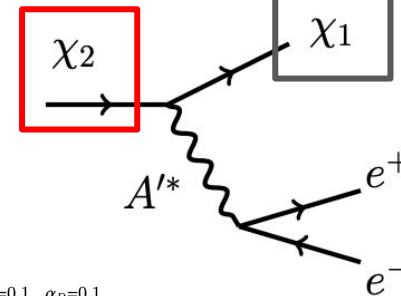


Inelastic DM generally  
does not change the  
relic bounds much, but  
adds new signatures

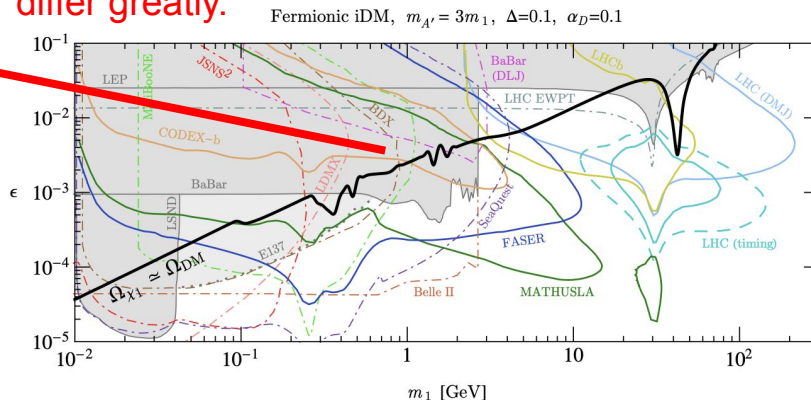
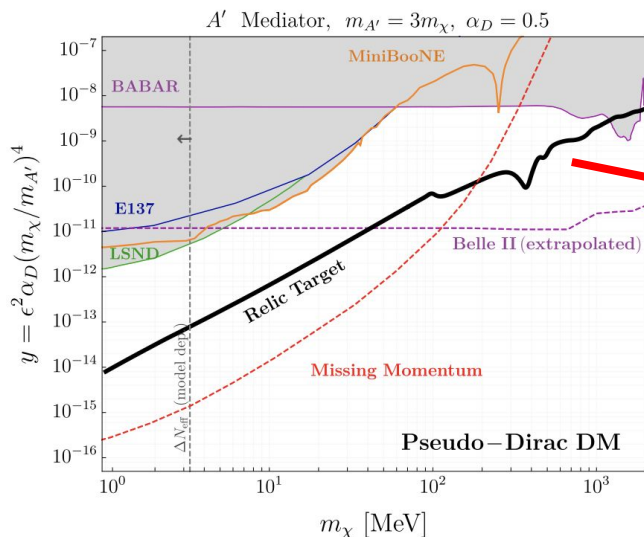
# Inelastic DM: Example of a minimal extension

- By adding new signatures we make it easier to detect
  - Simple extension of the model changes bounds a lot
  - A case where many detectors can play a role

Additional  
unstable DM



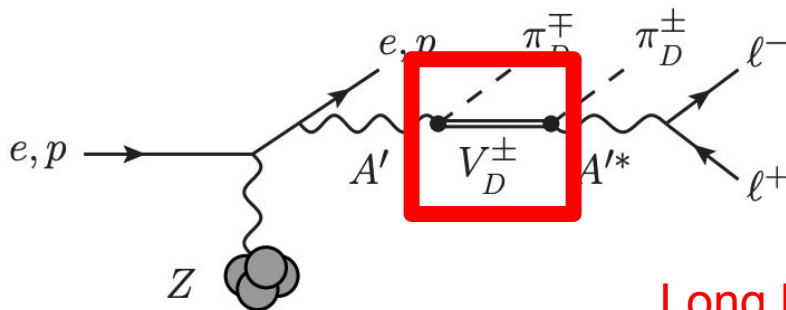
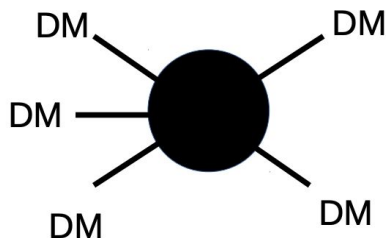
Relic Targets are roughly the same. However bounds from experiments differ greatly.



+Strong Bounds from LHC and Beam dump

# SIMP DM model

- Strongly Interacting Massive Particle (SIMPs)
  - Dark sector has a  $SU(N_c)$  dark that explains DM
    - Yields Dark QCD particles ( $\pi_D, V_D$ ) akin to ( $\pi, \omega, \phi, \dots$ )
  - Originally motivated by 3 to 2 processes, which gives relic
  - Naturally forces a DM scale of 100 MeV
  - Also motivates long lived signatures naturally from model

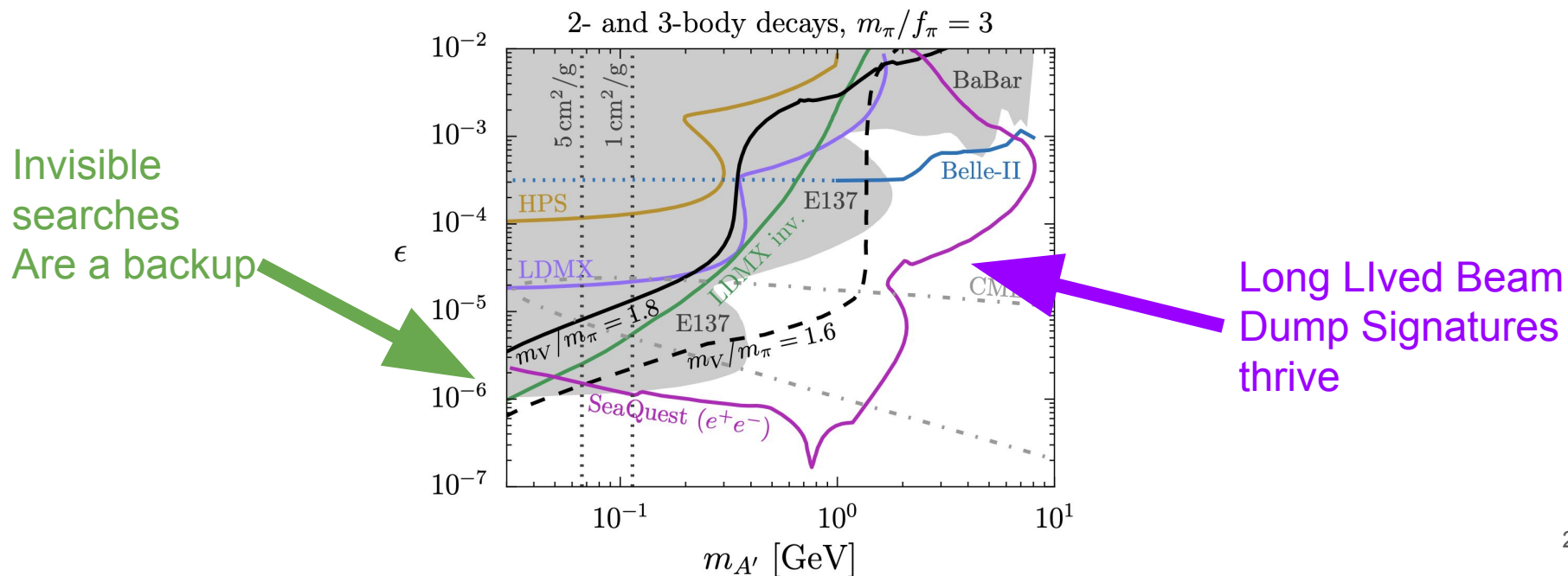


Key Target

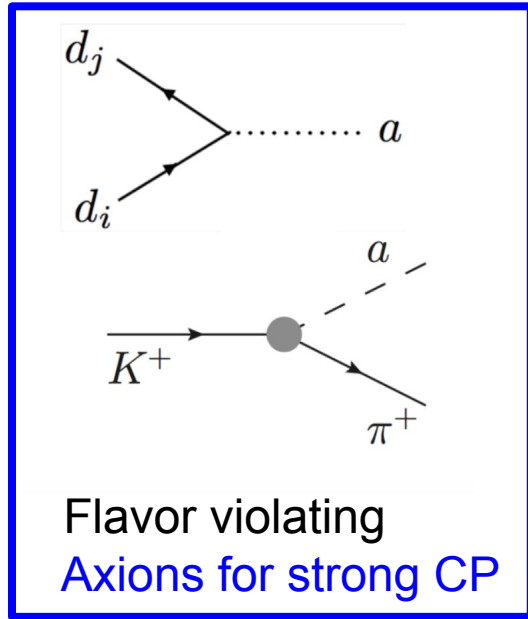
Long Lived Signatures

# SIMP DM model: Bounds

- Core feature is the long lifetime signature
  - Potentially exploration with LHC based searches can help

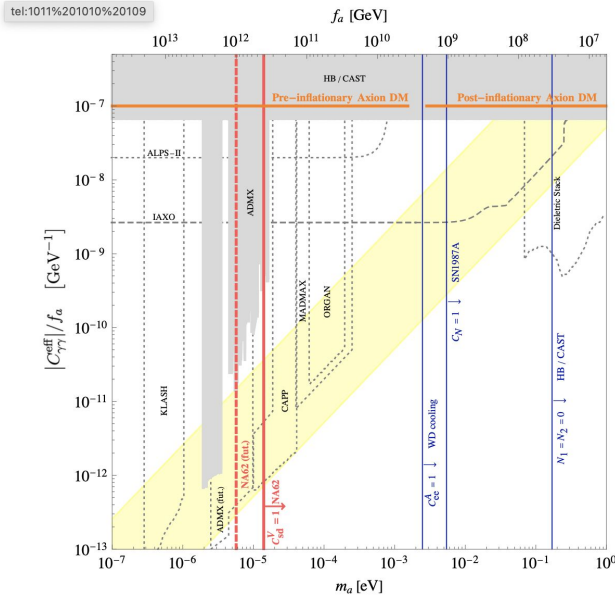
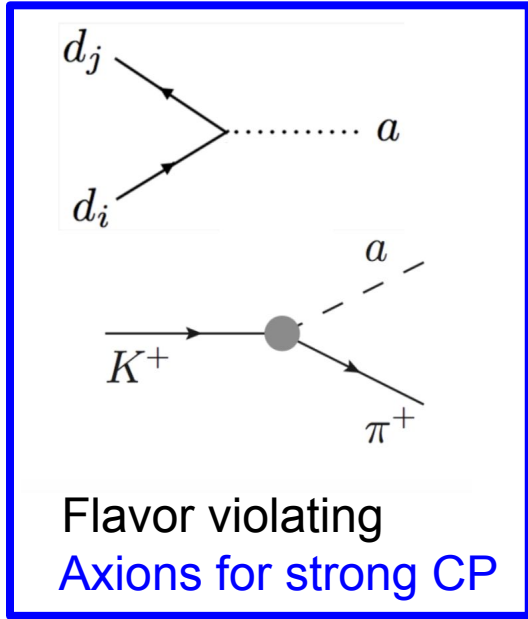


## Big Idea 3: Motivated Theory Extensions



Can we explain core theory features with extended model

# Big Idea 3: Motivated Theory Extensions



$$K \rightarrow \pi a$$

Measuring Kaon  
decays probes flavor  
structure

Can we explain core theory features with extended model

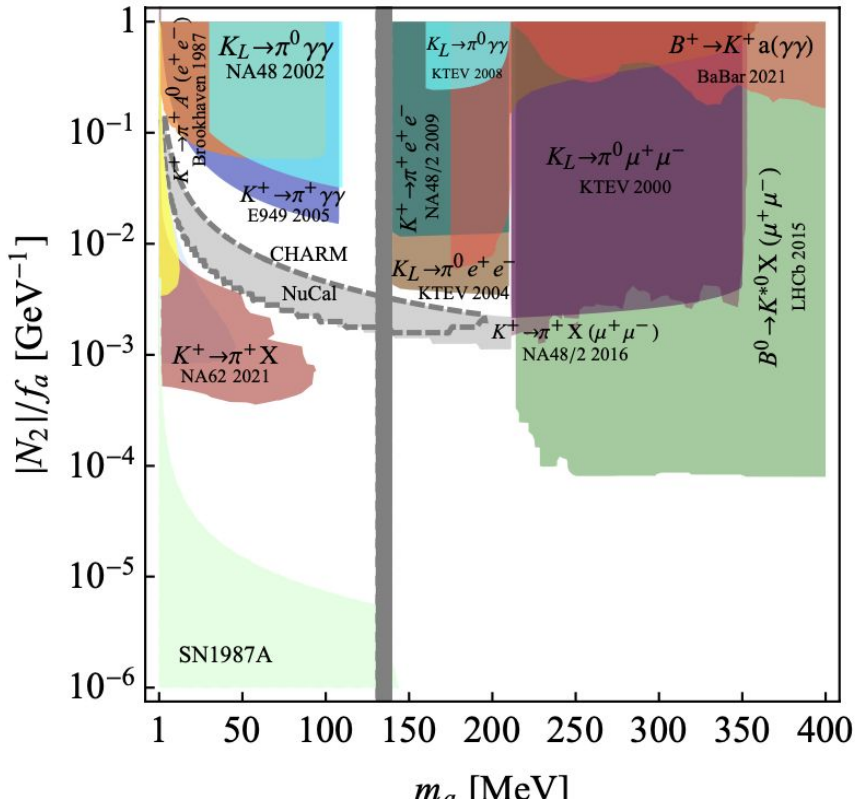
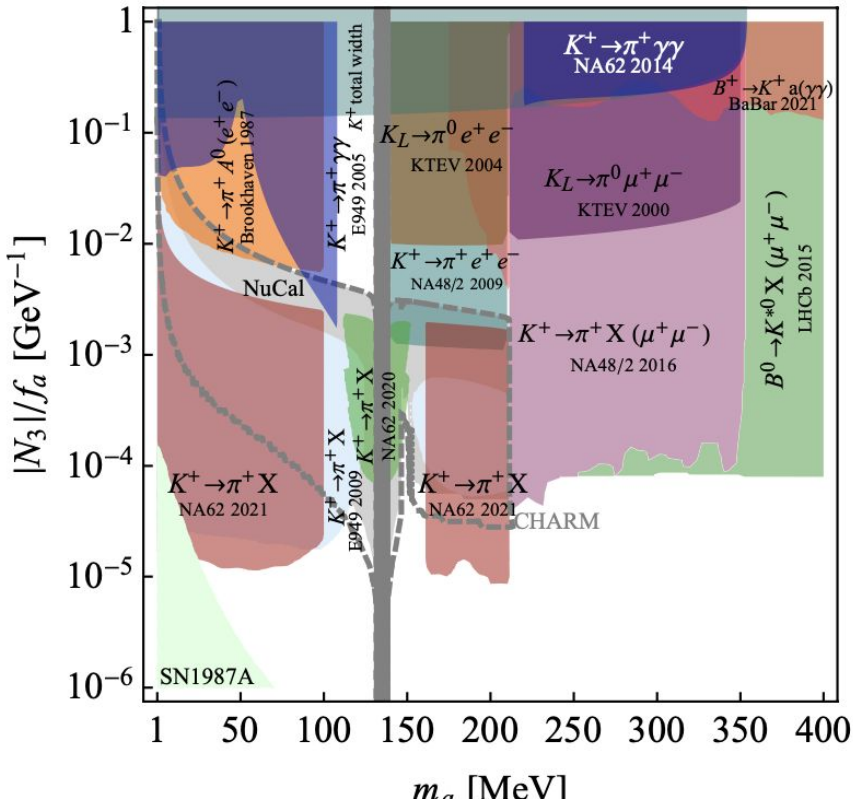
# Flavor Violating axions

- One can envision the QCD axion as a dark matter candidate
  - Axion couplings are very sensitive in Kaon decays
  - Can probe a very high scale in axions (Dim 5)
    - Lead to a probe of the QCD Axion
- X

$$\mathcal{L}_{\text{ALP-photon}} = \frac{\alpha}{8\pi f_a} C_{\gamma\gamma}^{\text{eff}} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$C_{\gamma\gamma}^{\text{eff}}(m_a) = N_1 + N_2 + \sum_q 6 Q_q^2 C_{qq}^A(\mu_0) B_1(\tau_q) + 2 \sum_{\ell} C_{\ell\ell}^A B_1(\tau_{\ell})$$

# More Axioms



# What needs to be done

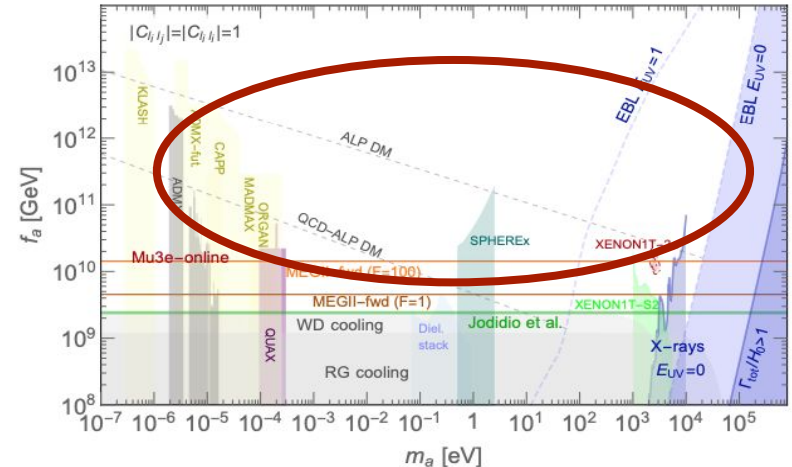
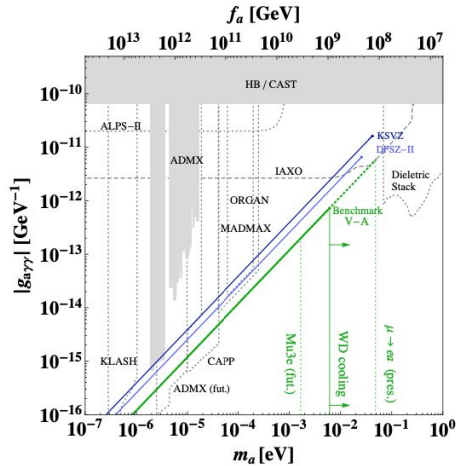
- Add Mike's messaging suggestions:
  - exploiting capabilities of existing large multi-purpose detectors + near-future upgrades;
  - Investing in specialized small-scale experiments + Investing in facilities that can deliver high-intensity beams;
  - Supporting the theory community to further develop theory of dark sector
- Additional Suggestions from Stefania
  - Is there a way to highlight more BSM physics?
  - Highlight secondary muon beams

# Backup

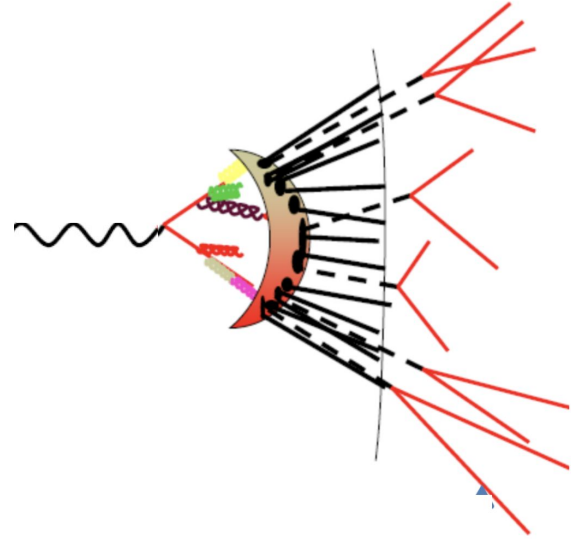
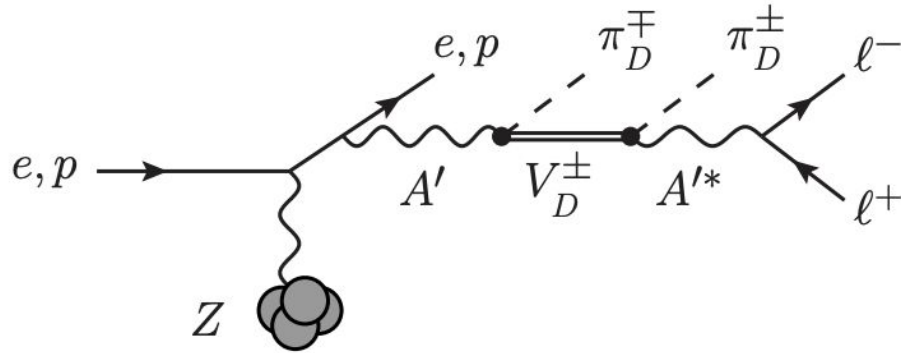
# Lepton flavor violating ALP as dark matter candidate

- If light enough ALP can be a DM candidate
  - If flavor violating couplings, can probe very high scales
  - For instance, for LFV couplings  $\mu \rightarrow e a$
  - Could be the QCD axion

2006.04795



## Big Idea 3: Theory Motivations



Or just a full on question  
what happens when things get complicated?  
Are we covering all signatures?

# Big Idea 3

## Benchmarks in Final State x Portal Organization

	DM Production	Mediator Decay Via Portal	Structure of Dark Sector
Vector	$m_\chi$ vs. $y$ [ $m_A/m_\chi=3, a_0=.5$ ] $m_{A'}$ vs. $y$ [ $a_0=0.5$ , 3 $m_\chi$ values] $m_\chi$ vs. $a_0$ [ $m_A/m_\chi=3, y=y_0$ ] $m_\chi$ vs. $m_A$ [ $a_0=0.5, y=y_0$ ] <i>Millicharge <math>m</math> vs. <math>q</math></i>	$m_{A'}$ vs. $\epsilon$ [decay-mode agnostic] $m_{A'}$ vs. $\epsilon$ [decays]	<b>iDM <math>m_\chi</math> vs. <math>y</math></b> [ $m_A/m_\chi=3, a_0=.5$ ] (anom connection) <b>SIMP-motivated cascades [slices TBD]</b> $U(1)_{B-L} / \mu\text{-}\tau / B\text{-}\tau$ (DM or SM decays)
Scalar	$m_\chi$ vs. $\sin\theta$ [ $\lambda=0$ , fix $m_S/m_\chi, g_D$ ] (thermal target excluded 1512.04119, should still include) Note secluded DM relevance of $S \rightarrow \text{SM}$ of mediator searches	$m_S$ vs. $\sin\theta$ [ $\lambda=0$ ] $m_S$ vs. $\sin\theta$ [ $\lambda=\text{s.t. Br}(H \rightarrow \phi\phi) \sim 10^{-2}$ ]?	Dark Higgsstrahlung (w/vector) scalar SIMP models? Leptophilic/leptophobic dark Higgs?
Neutrino	$e/\mu/\tau$ a la 1709.07001?	$m_N$ vs. $U_e$ $m_N$ vs. $U_\mu$ $m_N$ vs. $U_\tau$ Think more about reasonable flavor structures	Sterile neutrinos with new forces?
ALP	$m_\chi$ vs. $f_q/l$ [ $\lambda=0$ , fix $m_a/m_\chi, g_D$ ] (thermal target excluded) What about $f_\gamma, f_g$ ?	$m_a$ vs. $f_\gamma$ $m_a$ vs. $f_g$ $m_a$ vs. $f_q=f_l$ (separate?) Think more about reasonable coupling relations including $f_{WZ}$	FV axion couplings

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

# What distinguishes Big Idea 3 from the rest?

- ***Framing Big Idea 3:*** Even if dark sectors have non-minimal structures, either in couplings to the standard model, or the dark sector spectra of states, they can still be efficiently searched for in high intensity experiments.
- ***Framing Big Idea 1:*** Dark matter particles can be observably produced at intensity-frontier experiments, and opportunities in the next decade will explore important parameter space motivated by thermal DM models, the dark sector paradigm, and anomalies in data.
- ***Tentative Framing of Big Idea 2:*** Light, weakly coupled mediators to a dark sector can be copiously produced in high-intensity experiments and detected through their decays to Standard Model particles. Existing, planned, and proposed experiments offer great potential to discover the mediator and discern the pattern of its interactions with ordinary matter.

# Points from Stefania

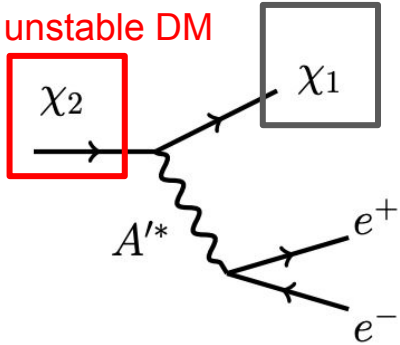
1. Can we highlight more theory BSM anomalies
2. Point out that SIMPs introduce a scale of 100 MeV naturally
3. Make a stronger statement about iDM
5. SIMP Naturally predict LLPs
6. Highlight secondary muon beams from future proton beam dumps

# Points from Mike

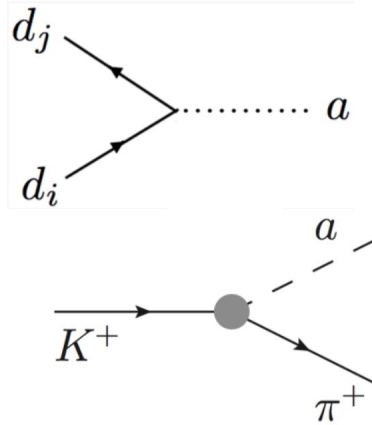
- \* exploiting the capabilities of existing large multi-purpose detectors, including near-future upgrades;
- \* investing in specialized small-scale experiments, and in facilities that can deliver high-intensity beams;
- \* and supporting the theory community to further develop the theory of dark-sector physics.

# Big Idea 3: Theory Motivations

Additional  
unstable DM

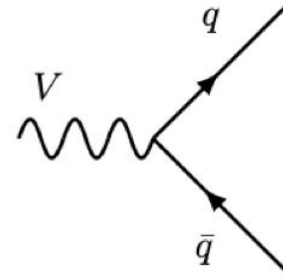


Inelastic DM  
(Simple  
extension)



Flavor violating  
Axions for strong CP

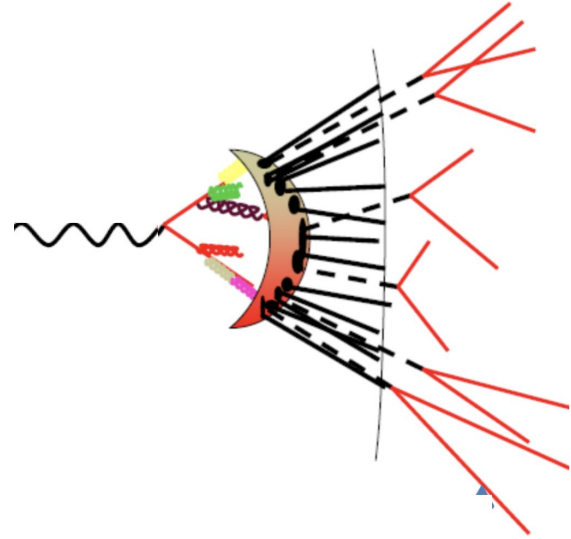
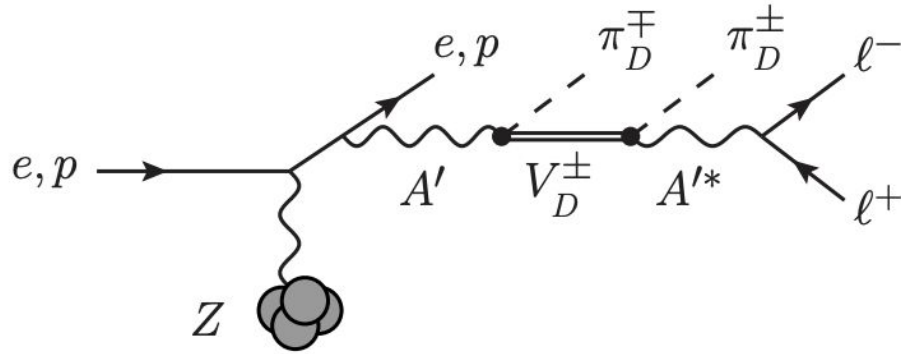
$V \rightarrow \text{hadrons}$



Hadrophilic DM  
To avoid existing bounds

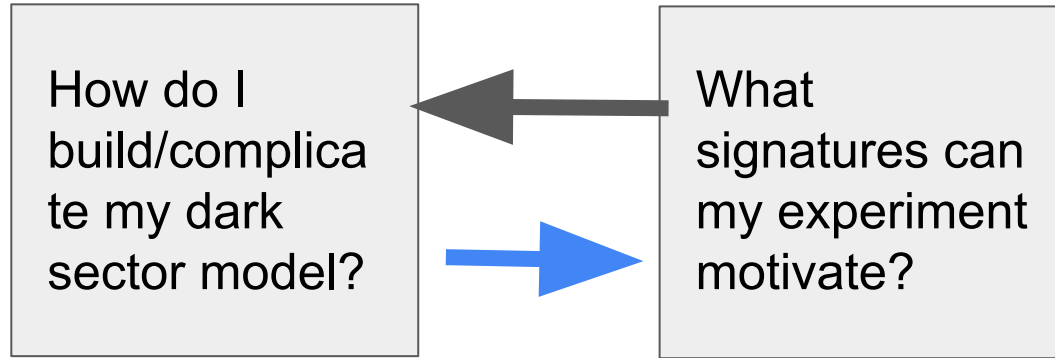
Additionally theoretical motivations to make things more complicated

## Big Idea 3: Theory Motivations



Or just a full on question  
what happens when things get complicated?  
Are we covering all signatures?

# Additional Backdrop



Small extensions of models can lead to many new signatures at experiments

Being experimentally prepared for well motivated extensions should be goal of next generation experiments

# Proposed Outline of the paper

- Framing of Big Idea 3 amongst the other Big Ideas
- Big Idea 3 Motivations and Scope
  - Extended Dark Sector
  - Physics Anomalies
  - Additional Motivations
- Benchmark Models and Motivations
  - Review of the LOIs and how they fit into their papers
- Mapping of models to Experimental Approaches
  - Full discussion of experimental approaches will go in Big Ideas 4

# Motivating Models for Big Idea 3

- Extended/non-minimal dark sectors
  - Minimality is good but may not correspond to reality (example: SM)
- Which models to present?
  - Strongly motivated theoretically (example: flavor violating QCD axion)
  - Highlighting experimental reach:
    - What do we learn about a model if nothing is found (example: closing the prompt decaying ALP window below kaon mass)
- Finding Benchmarks for all models can be a challenge
  - A key point of the Big Ideas 3 is to collect the motivations for extension
  - Allows us to have a benchmark

# Data Anomalies that help promote Big Idea 3

- $(g-2)_\mu$
- B Physics anomalies
  - RK and other flavor anomalies
- Xenon 1T
- MiniBoone Excess
- Beryllium
- Neutron lifetime anomaly
- KOTO

Discussion: How complicated a model is needed to motivate these?

How complicated a detector is needed to find these models?

# Examples

Questions to keep in mind for discussion

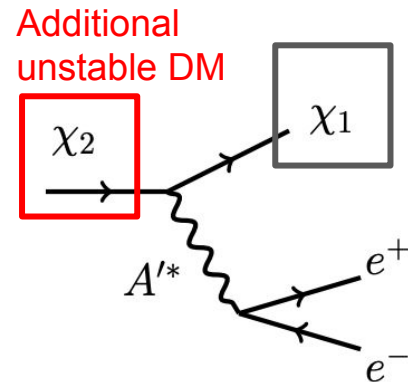
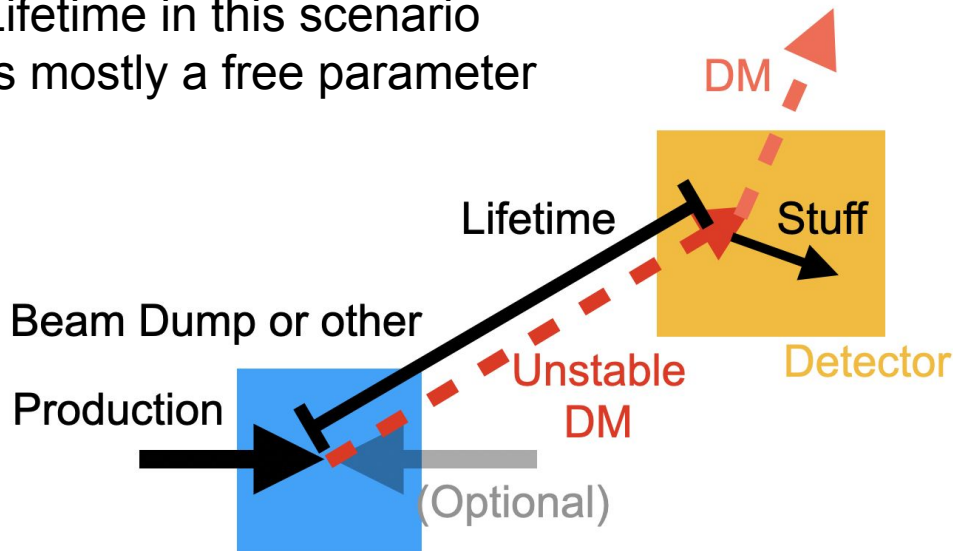
How do we prepare ourselves for newer, more complicated models?

Discussion: What do we define as complete or adequate signature coverage?

# Inelastic DM: Example of a minimal extension

- Strategy start with one of our usual portals:
  - Modify the Dark Matter to have an unstable candidate

Lifetime in this scenario  
Is mostly a free parameter

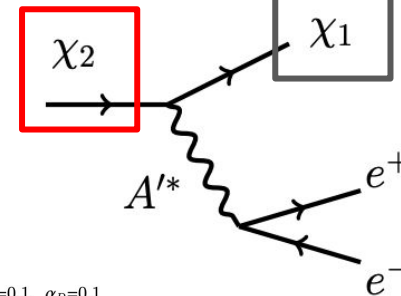


Inelastic DM generally  
does not change the  
relic bounds, but **adds  
new signatures**

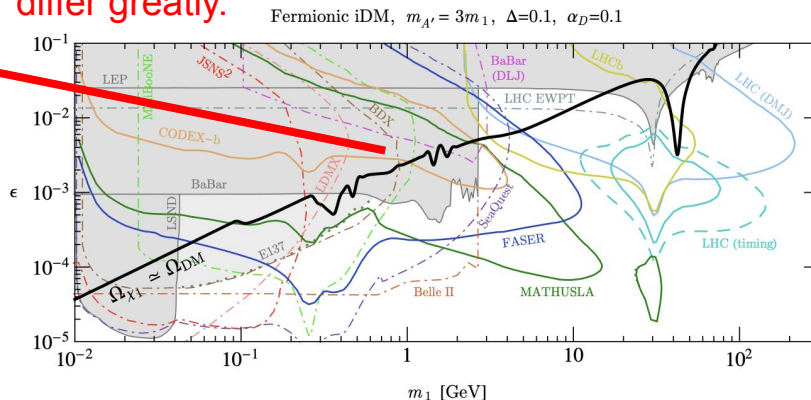
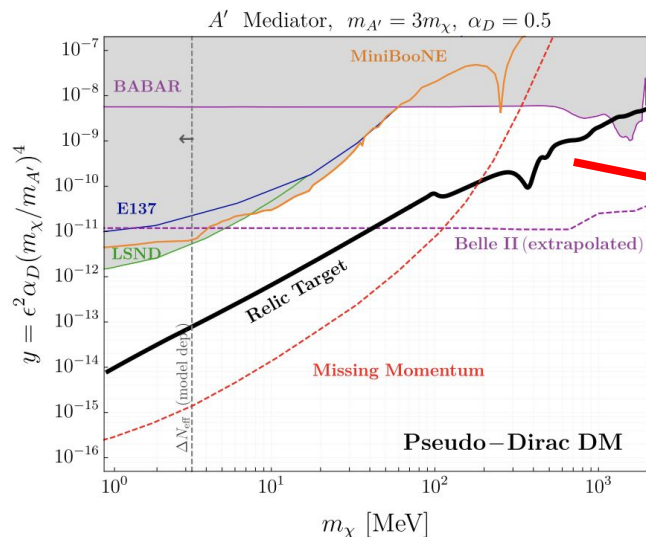
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Additional  
unstable DM



Relic Targets are roughly the same. However bounds from experiments differ greatly.



# Long Lived particles as an extension of dark sector

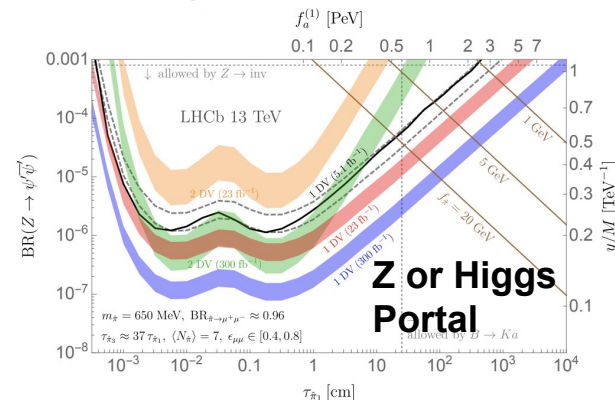
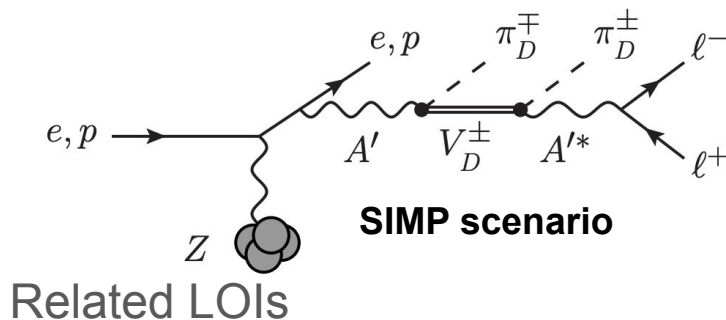
- Adding an unstable DM is a simple extension to dark sector
  - Leads to a wealth of other new final states
- More flexibility of signatures than just portals with small couplings

## **Related LOIs that cover this**

- BDF/SHiP facility AF5\_AF0-RF6\_RF0-163
- LLP at Energy Frontier EF9\_EF10-RF6\_RF0-TF7\_TF8\_James\_Beacham-201
- LLP at FCC-ee EF8\_EF9-RF6\_RF0\_Rebeca\_Gonzalez\_Suarez-147
- New light particles at ILC main beam dump EF9\_EF0-RF0\_RF6-086.
- Codex-b EF9\_EF0-RF6\_RF0-034
- Electron fixed target spectrometer : HPS RF6\_RF0\_Nelson-078
- Proton fixed target spectrometer : DarkQuest RF6\_RF0\_Nhan\_Tran-025

# More complex Dark sector: Dark Pion

- Dark Pions, Dark Vector Mesons as a further extension
  - More complicated Dar Sector Scenario
  - Broad range of complex decays many of them can be **long lived**

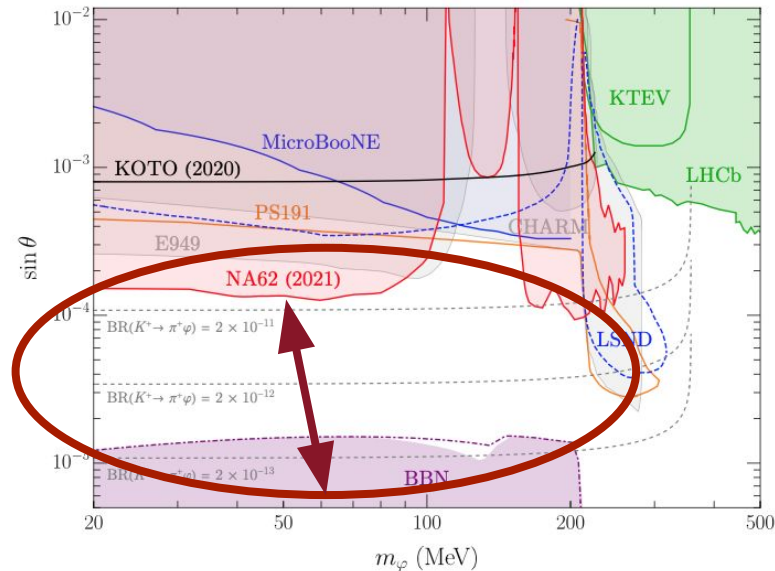


- Dark Pion Searches at LHC and High Intensities EF9\_EF10-RF6\_RF0-075
- LDMX RF6\_RF0-EF10\_EF0-CF1\_CF0\_Andrew\_Whitbeck-104
- Electron fixed target spectrometer : HPS RF6\_RF0\_Nelson-078
- Proton fixed target spectrometer : DarkQuest RF6\_RF0\_Nhan\_Tran-025

# Connecting Portals with bounds: Higgs mixed scalar

Higgs Portal : one of the minimal portals ( Big Idea 1 and 2)

Next generation(s) of charged kaon experiments can close low mass allowed region



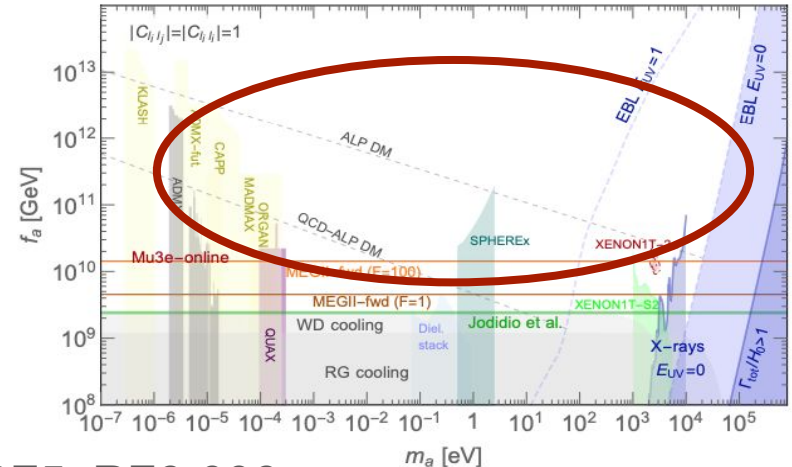
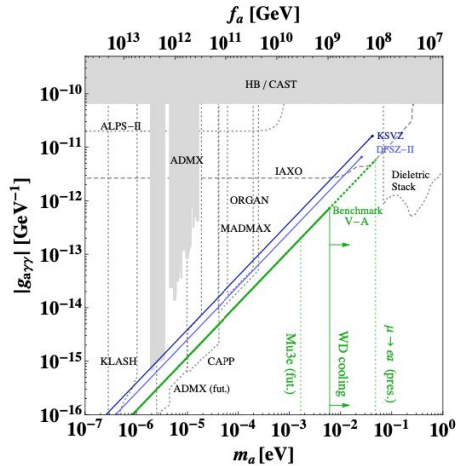
Bridge the gap with  
next generation Kaon  
experiments

2201.07805

# Lepton flavor violating ALP as dark matter candidate

- If light enough ALP can be a DM candidate
  - If flavor violating couplings, can probe very high scales
  - For instance, for LFV couplings  $\mu \rightarrow e a$
  - Could be the QCD axion

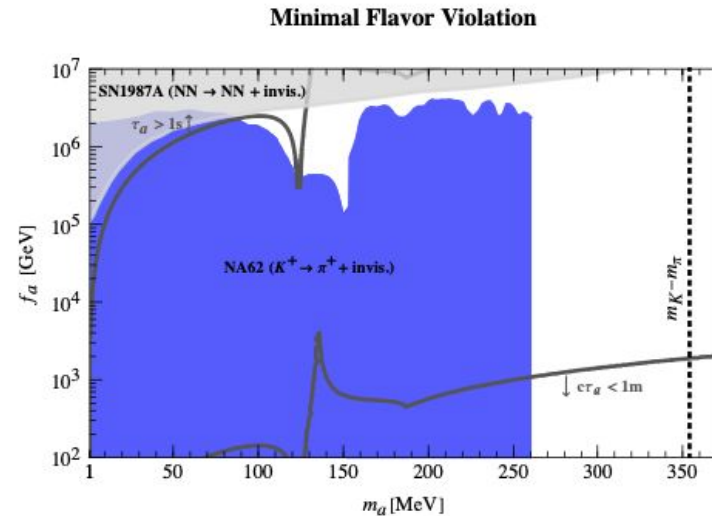
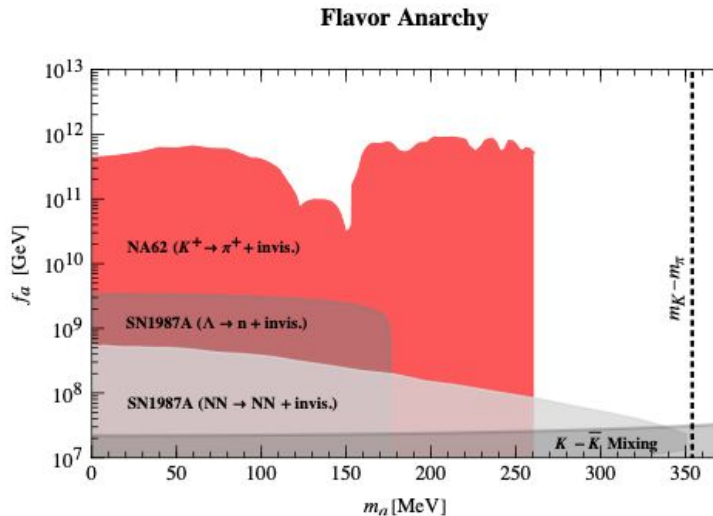
2006.04795



# ALP couplings to quarks

- Flavor violating couplings can translate to drastically different bounds on the parameters of the model
- Example: bounds on  $f_a$  for ALPs

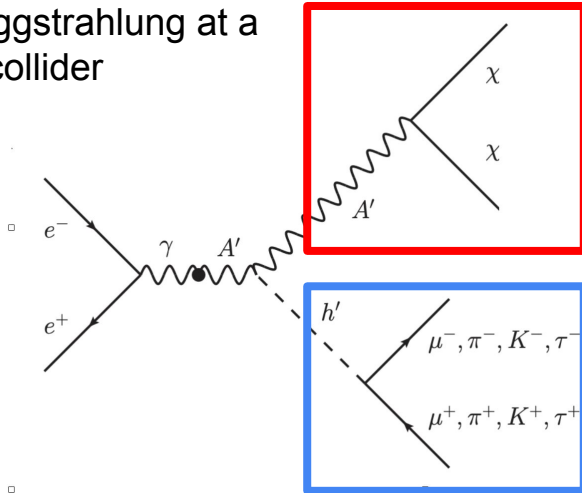
2201.07805



# Adding Both a Dark Higgs and a Dark Photon

- Dark Higgs is one way to give the dark photon a mass
- The addition of the Dark Higgs introduces lots of other possibilities
  - Effectively yields both light scalar and vector interactions
- Now have the possibility of multi light boson production

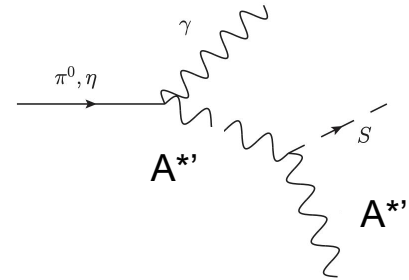
Dark higgstrahlung at a lepton collider



Dark Photon that can decay either visibly or invisibly

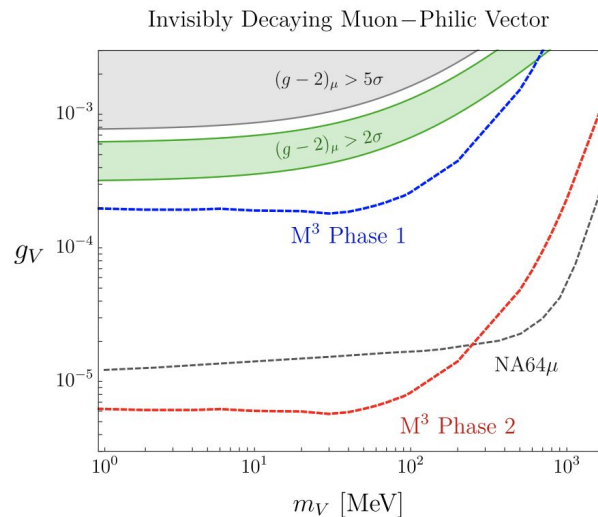
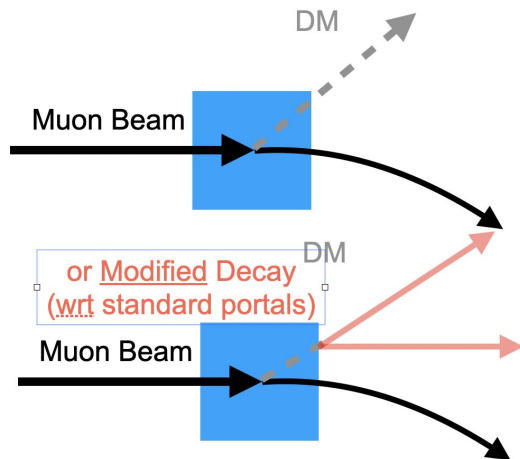
Dark Higgs with yukawa enhanced decays

Dark higgstrahlung in meson decays



# Models motivated by Physics anomalies

- $(g-2)_\mu$  is a major motivation for modified physics models
- Overall Strategy is to modify existing portal models
- Commonly used model for this is  $U(1)_{\mu-\tau}$
- Collection of other possible models will go in paper



# Motivated by anomalies

- A number of LOIs focus on modified models to explain g-2
- Additionally there is interest in models that are motivated by heavy flavor
- Another, motivated modification of the couplings also exist
  - Baryophilic
  - Hadrophilic
  - ...

## Related LOIs

- Light mediators and flavor anomalies (theory) RF6\_RF1\_Alakabha\_Datta-01
- LFV at FCCee RF6\_RF4-EF3\_EF4\_Mogens\_Dam-119

# Other Models

- Sexaquark Dark Matter

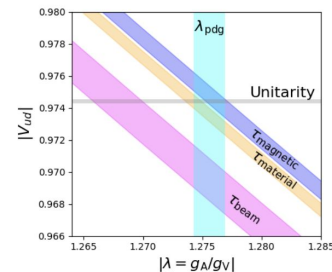
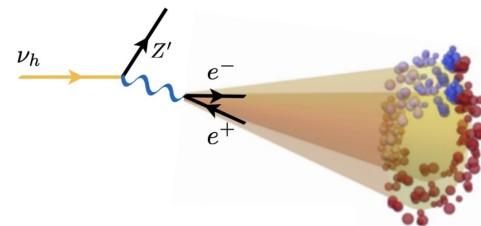
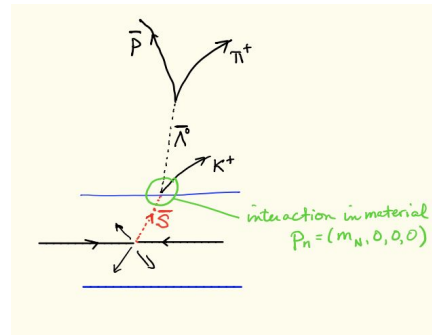
- Using Quarks to motivate Dark Matter, Distinct, rare signatures
- **LOI:** Delayed electroweak phase transition (theory)  
CF1\_CF0-EF7\_EF10- RF3\_RF6\_Glennys\_Farrar-198
- **LOI:** Accelerator search for color-flavor-spin singlet uuddss bound state DM CF1\_CF0-EF7\_EF10- RF3\_RF6\_Glennys\_Farrar-198

- Non minimal HNL models

- Modified HNL which can potentially explain excess like MiniBoone
- **LOI:** NF2\_NF3-EF9\_EF0-RF4\_RF6-CF1\_CF0-TF8\_TF11\_Matheus\_Hostert-041

- Neutron Portal Dark Matter

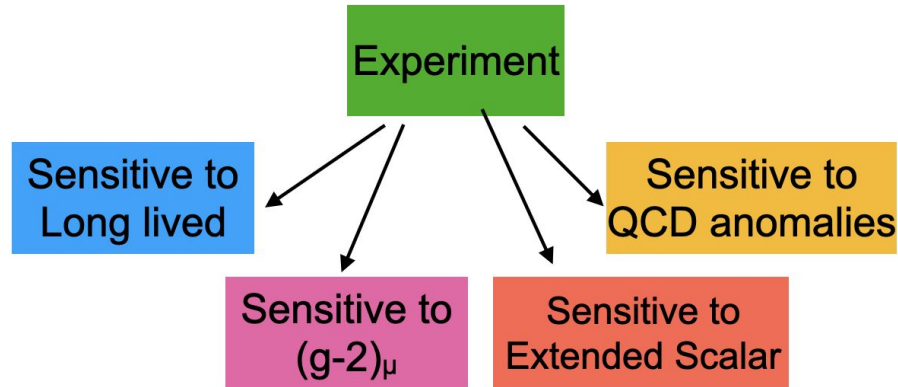
- **LOI:**  $\Delta B = 2$  RF4\_RF6-NF3\_NF10-TF2\_TF5\_Joshua\_Barrow-105
- **LOI:** Sterile neutrons at ORNL and ESS  
RF6\_RF3\_Joshua\_Barrow-115



# Experimental Signatures (and Motivations)

# General View of Experimental Connections

- When trying to construct a model or explain an anomaly
  - Certain experiments are emphasized over other experiments
- This can help to further motivate a specific experimental emphasis
- For Big Idea 3, we would like to highlight these extended motivations
  - And as a consequence, further highlight certain final states



- The full details of the experiments is left for Big Idea 4

# Beam Dump LOIs

Photon : Photon beam experiments RF6\_RF0-112

Neutrino beams : SNOWMASS21-NF3\_NF0-RF6\_RF0-CF1\_CF3-TF9\_TF11-148

Electron : LDMX RF6\_RF0-EF10\_EF0-CF1\_CF0\_Andrew\_Whitbeck-104

Electron fixed target spectrometer : HPS RF6\_RF0\_Nelson-078

Muon : Muon missing momentum RF6\_RF0-EF10\_EF0-CF1\_CF0\_Andrew\_Whitbeck-111

Proton fixed target spectrometer : DarkQuest RF6\_RF0\_Nhan\_Tran-025

Proton :1GeV proton beam dump at Fermilab RF6\_RF0-NF2\_NF3-AF2\_AF5-099

Proton: 10GeV proton beam dump at Fermilab RF6\_RF0-NF3\_NF0-AF5\_AF0-084

Kaon : Dark Sectors at NA62 & KLEVER — RF6\_RF0-011

Kaon: Dark Sectors at KOTO — RF6\_RF0\_KOTO-050

Kaon: Dark sectors at kaon factories (theory) — RF6\_RF0-034

Eta: Redtop RF2\_RF6-IF6\_IF3\_REDTOP\_Collaboration\_-\_new-083

Eta: Eta-Eta' factories RF6\_RF2\_Sean\_Tulin-117

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Enhanced by Dark  
Mesons/inelastic  
DM/Neutrino dipole

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Eta: Redtop RF2\_RF6-IF6\_IF3\_REDTOP\_Collaboration\_-\_new-083

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Enhanced by Dark  
Mesons/inelastic  
DM/Neutrino dipole

Enhanced by  
Extended Scalar/  
Heavy Flavor

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Enhanced by Dark  
Mesons/inelastic  
DM/Neutrino dipole

Enhanced by  
( $g-2$ ) <sub>$\mu$</sub>   
explanation

Enhanced by  
Extended Scalar/  
Heavy Flavor

Enhanced by  
explanation of QCD  
Anomalies

# High(er) Energy collider LOIs + Long Lived

Electron : LLP at Belle II RF6\_RF0\_Torben\_Ferber-020

Electron : ILC beam dump: EF9\_EF0-RF0\_RF6-086

Electron: LLP at FCCee EF8\_EF9-RF6\_RF0\_Rebeca\_Gonzalez\_Suarez-147

Proton : BDF/SHiP facility AF5\_AF0-RF6\_RF0-163

Proton : Forward Physics Facility : EF9\_EF6\_EF10\_EF5-NF6\_NF3\_NF10-RF6\_RF0-CF7\_CF0-AF5\_AF0-UF1\_UF2

Proton : Codex-b: EF9\_EF0-RF6\_RF0-034

FASER : EF9\_EF6-NF3\_NF6-RF6\_RF0-CF7\_CF0-AF5\_AF0\_FASER2

Mathusla: EF9\_EF10-NF3\_NF0-RF6\_RF0-AF5\_AF0-IF3\_IF7\_MATHUSLA\_(David\_Curtin)-184

Overview: LLP at EF EF9\_EF10-RF6\_RF0-TF7\_TF8\_James\_Beacham-201

# High(er) Energy collider LOIs + Long Lived

Enhanced by Dark  
Mesons/inelastic  
DM/Neutrino dipole

Electron : LLP at Belle II RF6\_RF0\_Torben\_Ferber-020

Electron : ILC beam dump: EF9\_EF0-RF0\_RF6-086

Electron: LLP at FCCee : EF8\_EF9-RF6\_RF0\_Rebeca\_Gonzalez\_Suarez-147

Proton : BDF/SHiP facility AF5\_AF0-RF6\_RF0-163

Proton : Forward Physics Facility : EF9\_EF6\_EF10\_EF5-NF6\_NF3\_NF10-RF6\_RF0-CF7\_CF0-AF5\_AF0-UF1\_UF2

Proton : Codex-b: EF9\_EF0-RF6\_RF0-034

Proton : FASER : EF9\_EF6-NF3\_NF6-RF6\_RF0-CF7\_CF0-AF5\_AF0\_FASER2

Proton : MATHUSLA: EF9\_EF10-NF3\_NF0-RF6\_RF0-AF5\_AF0-IF3\_IF7\_MATHUSLA\_(David\_Curti

Overview: LLP at EF EF9\_EF10-RF6\_RF0-TF7\_TF8\_James\_Beacham-201

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Proton : Forward Physics Facility : EF9\_EF6\_EF10\_EF5-NF6\_NF3\_....

Proton : Codex-b: EF9\_EF0-RF6\_RF0-034

Proton : FASER : EF9\_EF6-NF3\_NF6-RF6\_RF0-CF7\_CF0-AF5\_AF0\_FASER2

Proton : MATHUSLA: EF9\_EF10-NF3\_NF0-RF6\_RF0-AF5\_AF0-IF3\_IF7\_MATHUSLA\_(David\_Curti

Overview: LLP at EF EF9\_EF10-RF6\_RF0-TF7\_TF8\_James\_Beacham-201

Enhanced by Dark  
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DM/Neutrino dipole

Enhanced by  
Extended Scalar/  
Heavy Flavor

# High(er) Energy collider LOIs + Long Lived

Electron : LLP at Belle II RF6\_RF0\_Torben\_Ferber-020

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Proton : Codex-b: EF9\_EF0-RF6\_RF0-034

Proton : FASER : EF9\_EF6-NF3\_5\_AF0\_FASER2..

Proton : MATHUSLA: EF9\_EF10-NF3\_MATHUSLA\_(David\_Curti..

Overview: LLP at EF EF9\_EF10-RF6\_RF0-TF7\_TF8\_James\_Beacham-201

Enhanced by Dark  
Mesons/inelastic  
DM/Neutrino dipole

Enhanced by  
Extended Scalar/  
Heavy Flavor  
Enhanced by  
(g-2)<sub>μ</sub>  
explanation≈

# Discussion Points

- How much can we use existing anomalies to drive this paper?
- How exotic of a model should we include?
  - What is the right level to motivate DM measurements beyond portals
- How do we handle overlap with BI 1 and BI 3
  - It can be good to have some redundancy
- Are we missing something?

# Come and Contribute

- Please let us know (by email/...) if we have missed your stuff
- There have been many developments since the LOIs
  - A number of new interesting channels have emerged
  - We are eager to update this with the many ongoing developments
- Please let us know if you plan on contributing to this white paper

**Send an email to us with you contribution topic**

[zupanje@ucmail.uc.edu](mailto:zupanje@ucmail.uc.edu), [schuster@slac.stanford.edu](mailto:schuster@slac.stanford.edu), [pcharris@mit.edu](mailto:pcharris@mit.edu)

**Contributed white papers due by March 15th, 2022**

**Solicited whitepapers due by April 15th, 2022**

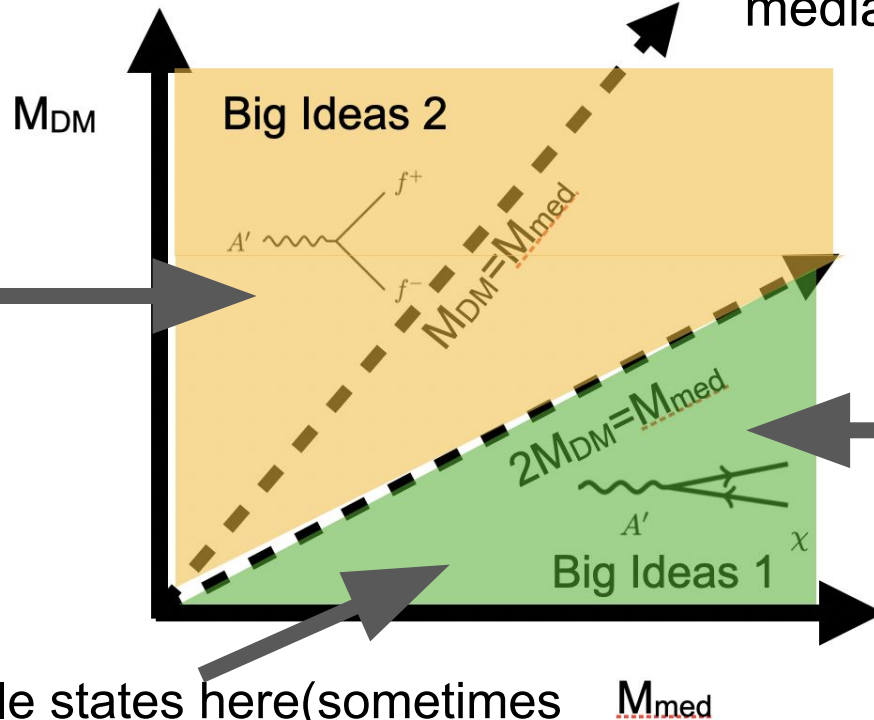
Thanks!

# Visualizing The Big Ideas

For a give model we can vary dark matter mass ( $M_{\text{DM}}$ ) and mediator mass ( $M_{\text{med}}$ )

## Big idea 2

Over here we look for visible decays from the dark matter



## Big idea 1

Over here we look for invisible decays or DM scatters

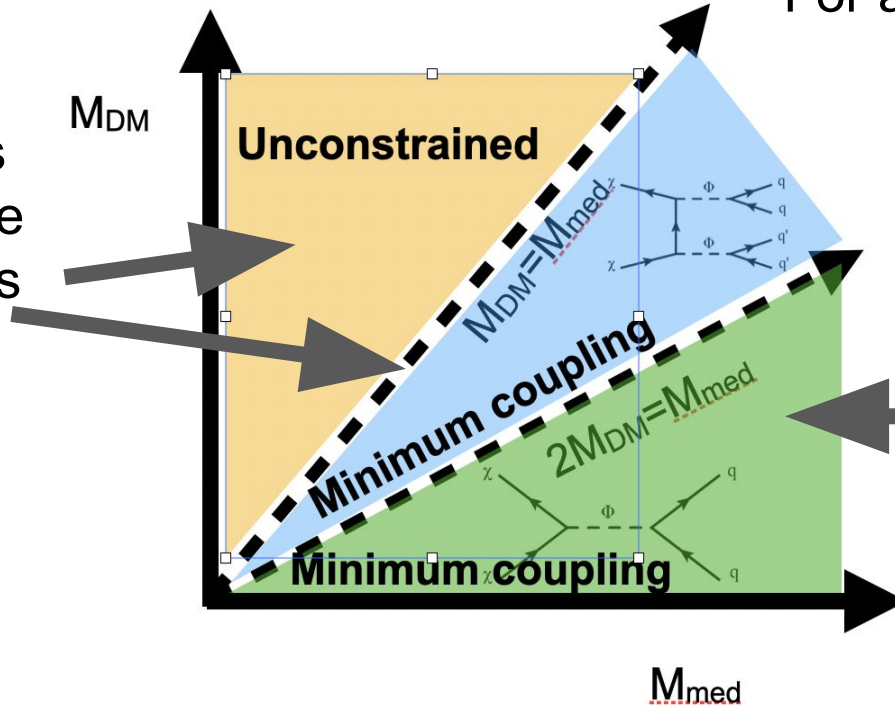
We still get visible states here (sometimes suppressed), also big idea 2

# Motivating The Big Ideas

For each model we can  
compute the minimal coupling  
For a thermal relic target

## Big idea 2

For DM that is  
lighter than the  
mediator mass  
Can find a  
minimum  
coupling  
otherwise no  
minima



## Big idea 1

Minimum  
coupling  
present  
(usually take  
 $\frac{1}{3} = M_{DM}/M_{med}$ )

Below the minimum, hard to get a thermal target

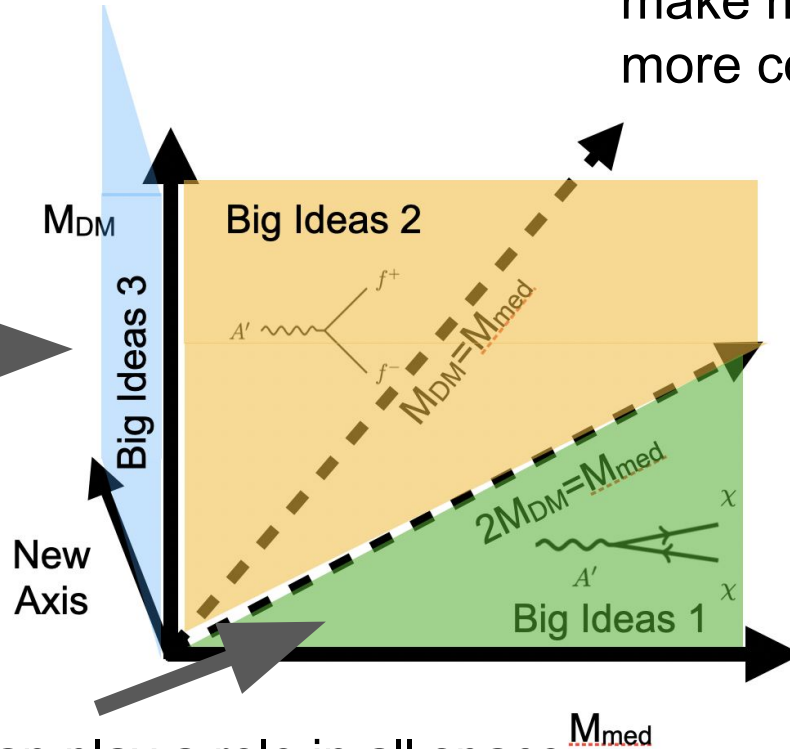
# Big Idea 3

## Big idea 3

What is another way to extend the model to enhance the physics performance

Visible and Invisible can play a role in all space once model is more complicated

With Big Idea 3 we aim to make models that are **slightly** more complicated



## Motivations

The extensions of the models need to be well motivated to ensure lack of simplicity