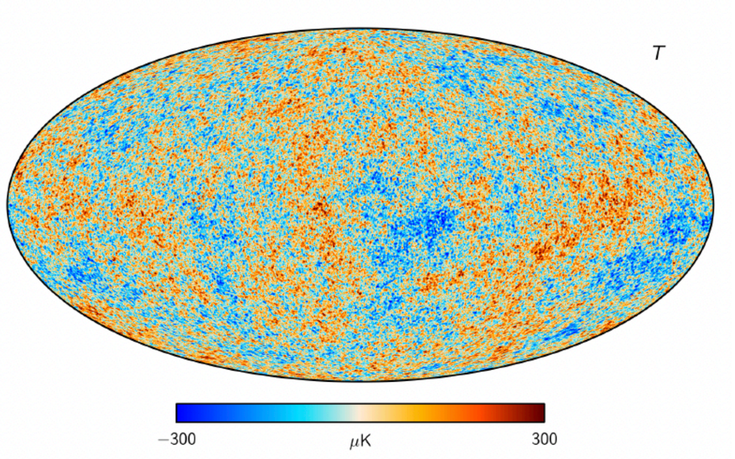
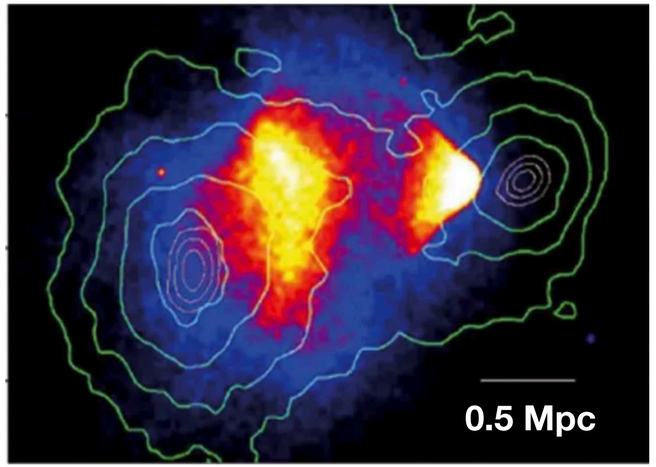
New ideas about DS at the intensity frontier

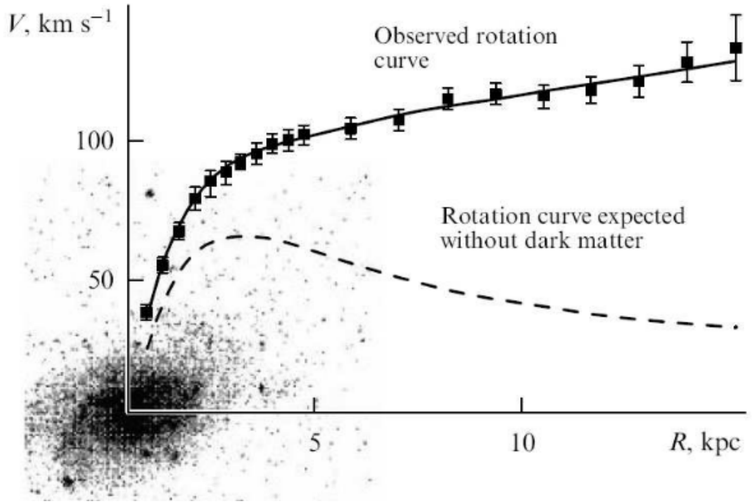
Marco Costa (Perimeter Institute)

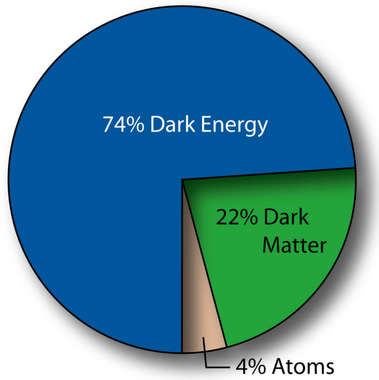
Evidence for DM



100 Mpc







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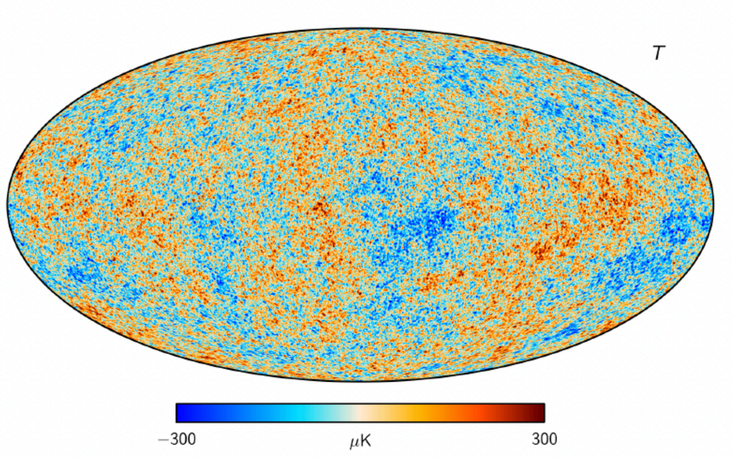

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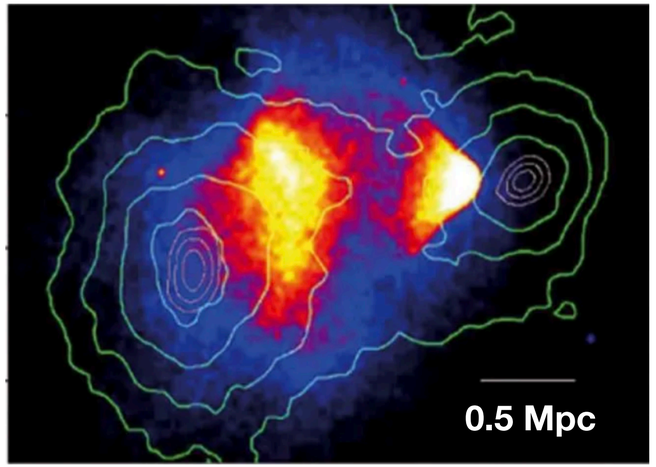
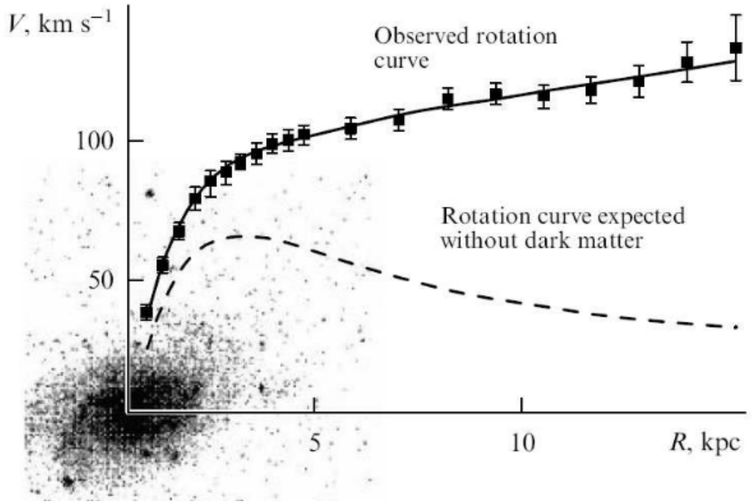
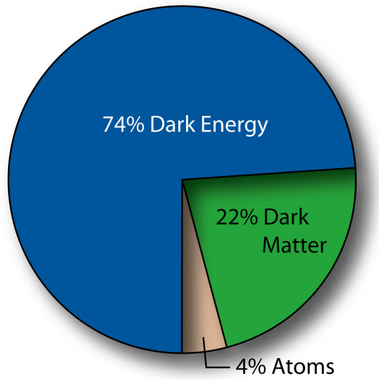


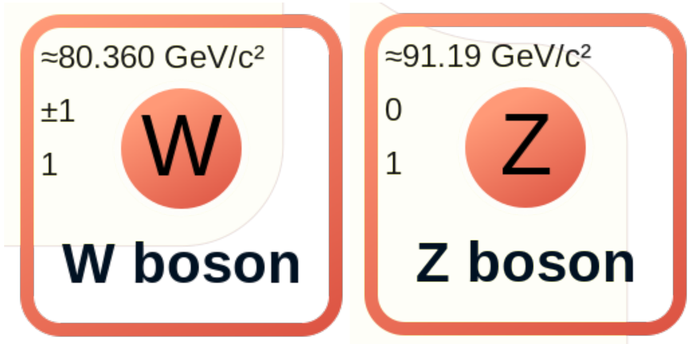




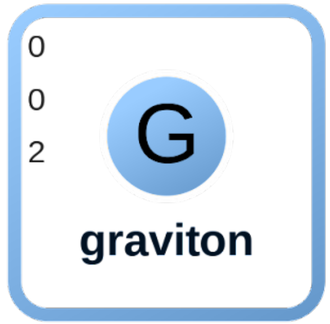
- Collisionless fluid
- Stable on cosmological timescales
- “Cold” (~ non-relativistic particle)
- Dominated by GR at large distance

Possible interactions?

SM-DM interactions

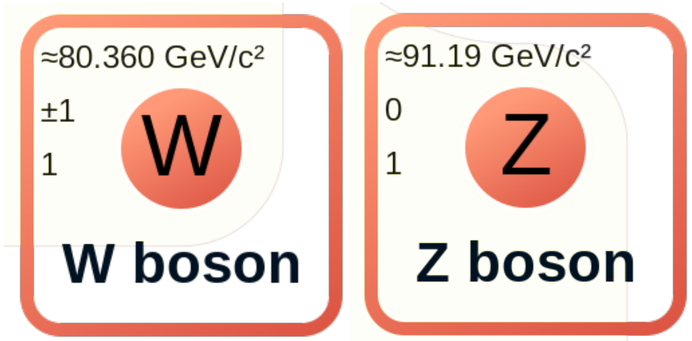


Optimist

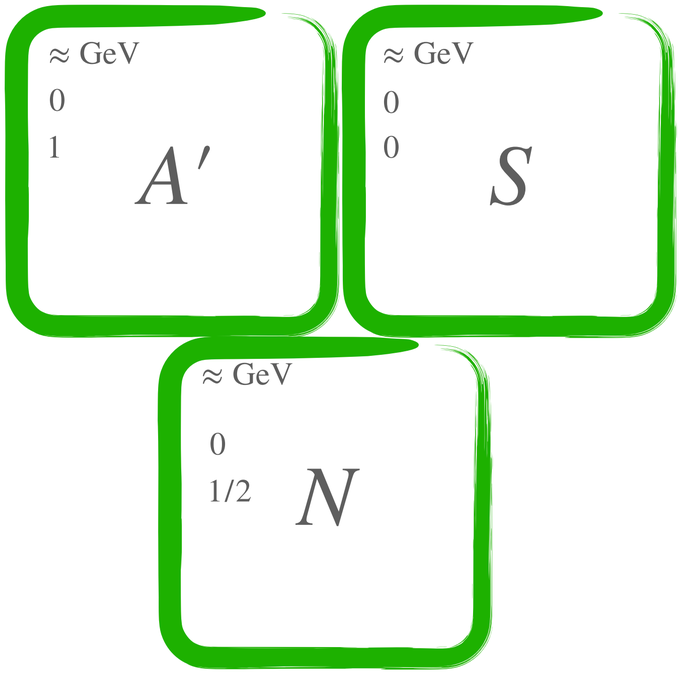


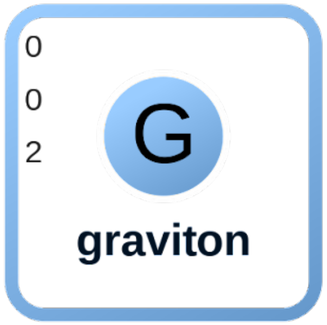
Pessimist

SM-DM interactions

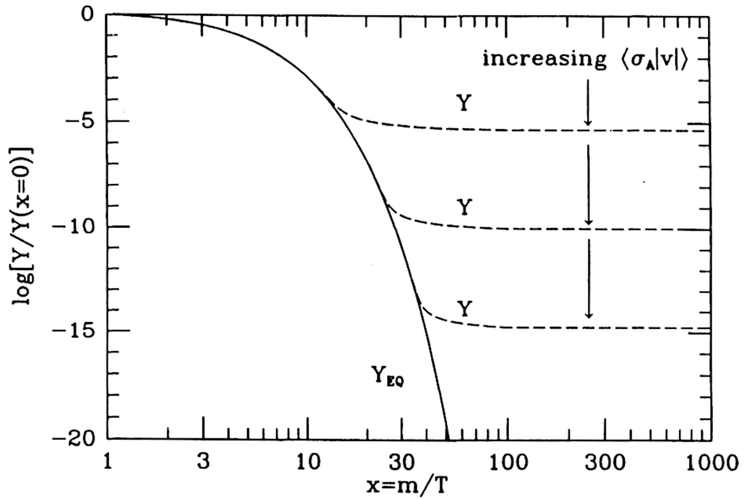


New portals!
For example…

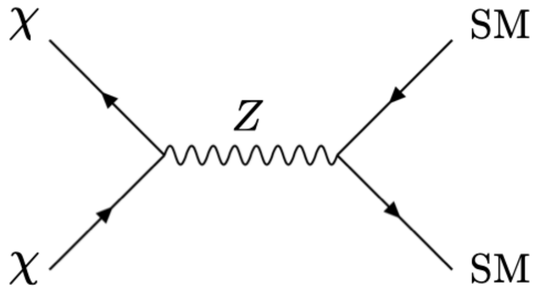




Mass range from freeze out



Standard WIMPS



$$\sigma v \sim \alpha_{\rm EW}^2 / m_\chi^2$$

$$m_\chi \sim \text{TeV}$$

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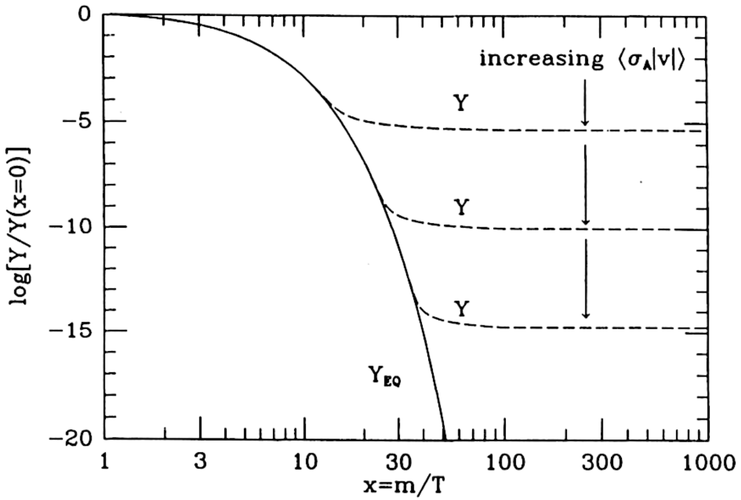

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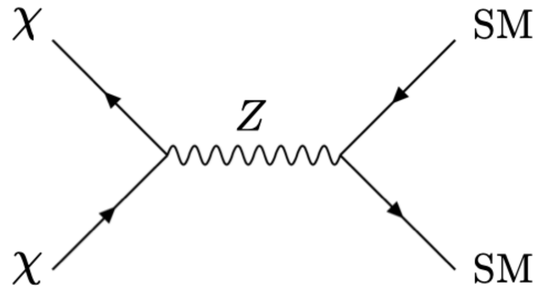

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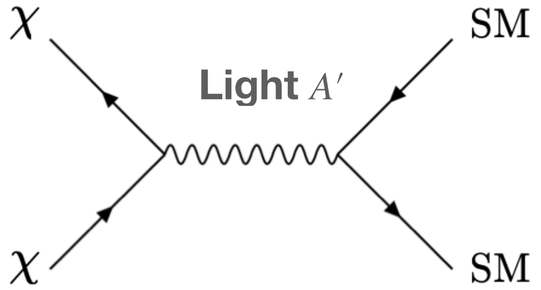
Light WIMPS

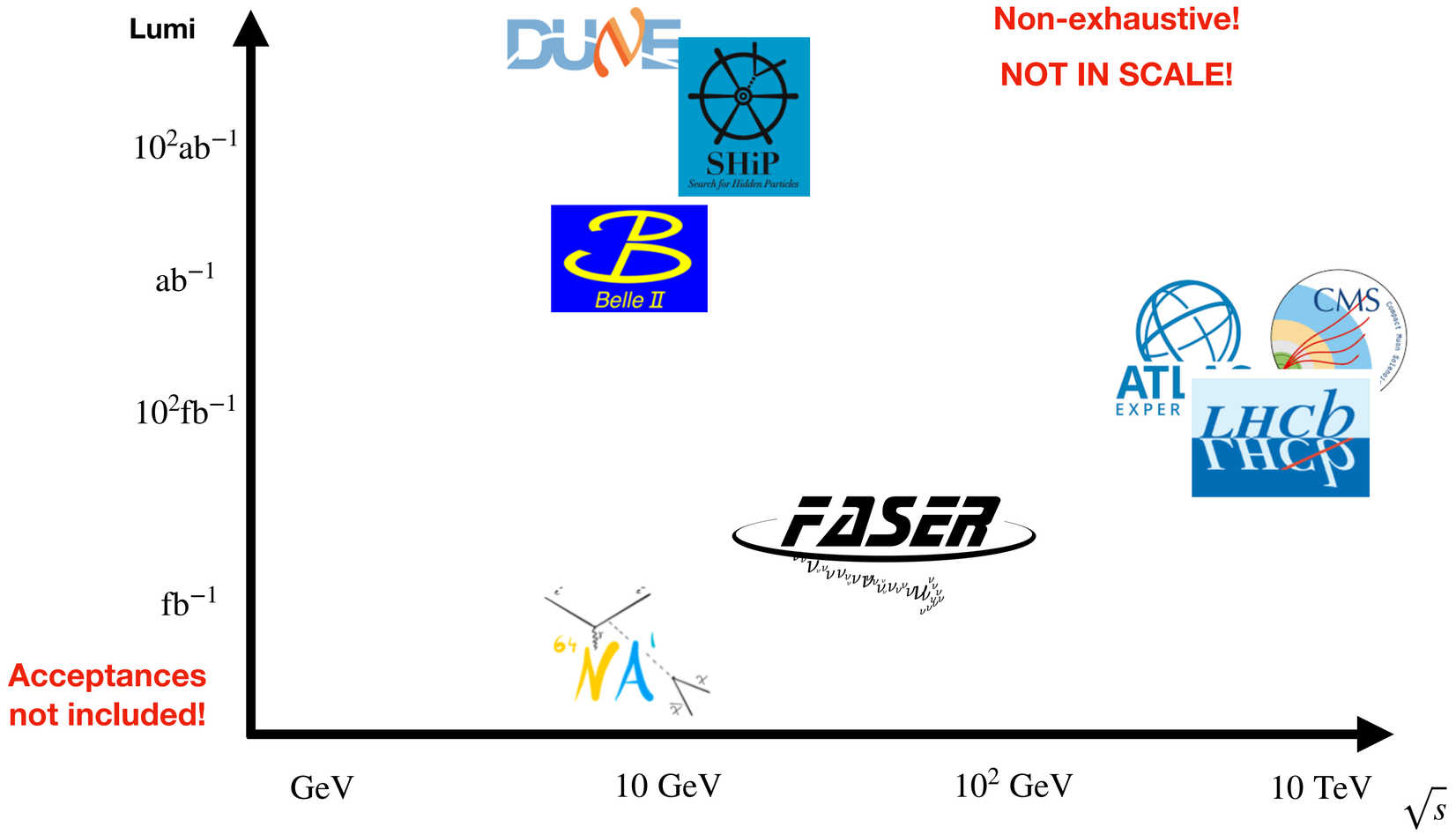


$$\sigma v \sim g_{\rm SM}^2 g_\chi^2 m_\chi^2 / m_{A'}^4$$

$$m_\chi \sim \text{MeV} \div \text{GeV}$$

Prime target for Intensity Experiment!

Experimental landscape



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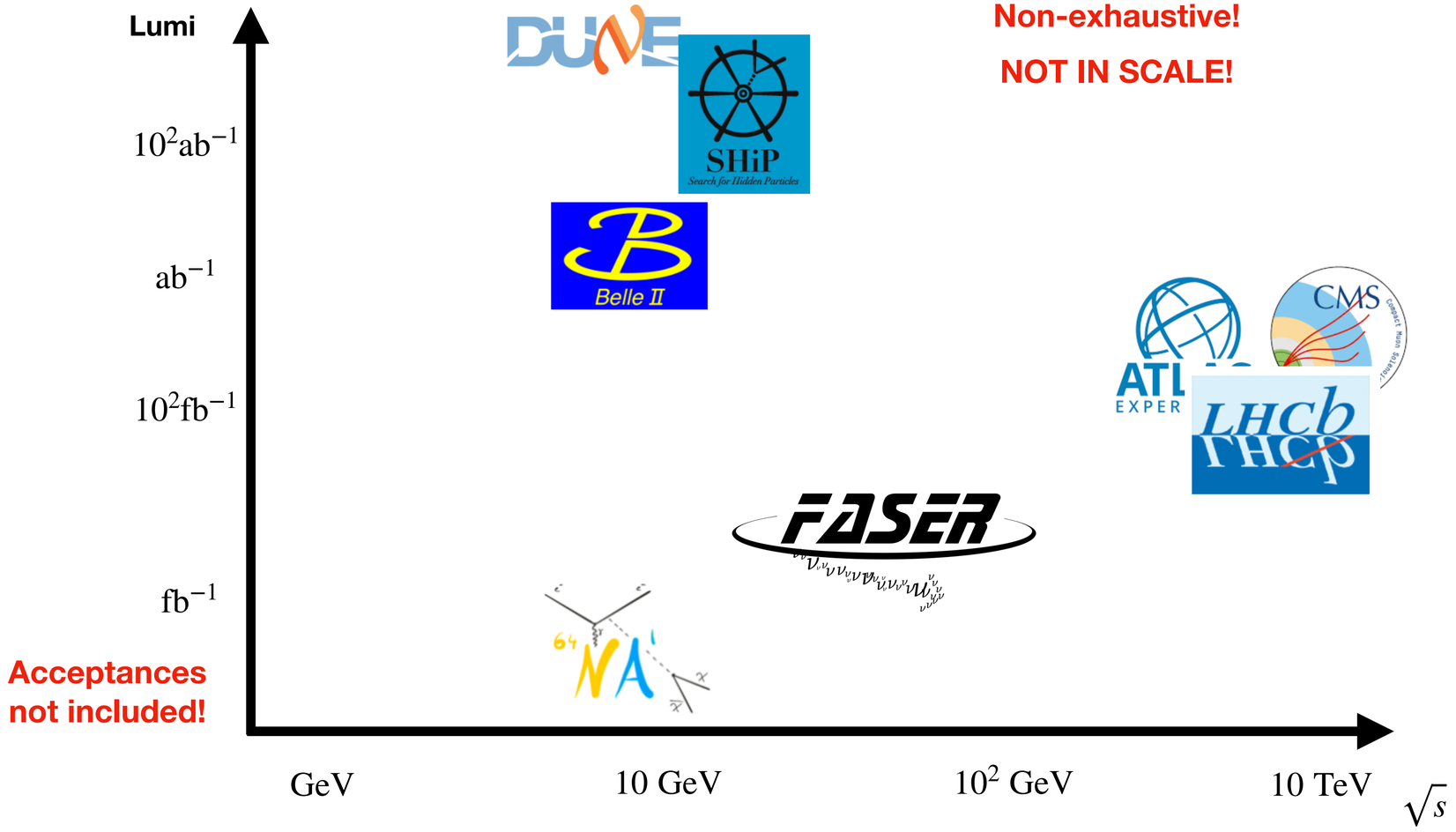


Non-exhaustive!

NOT IN SCALE!

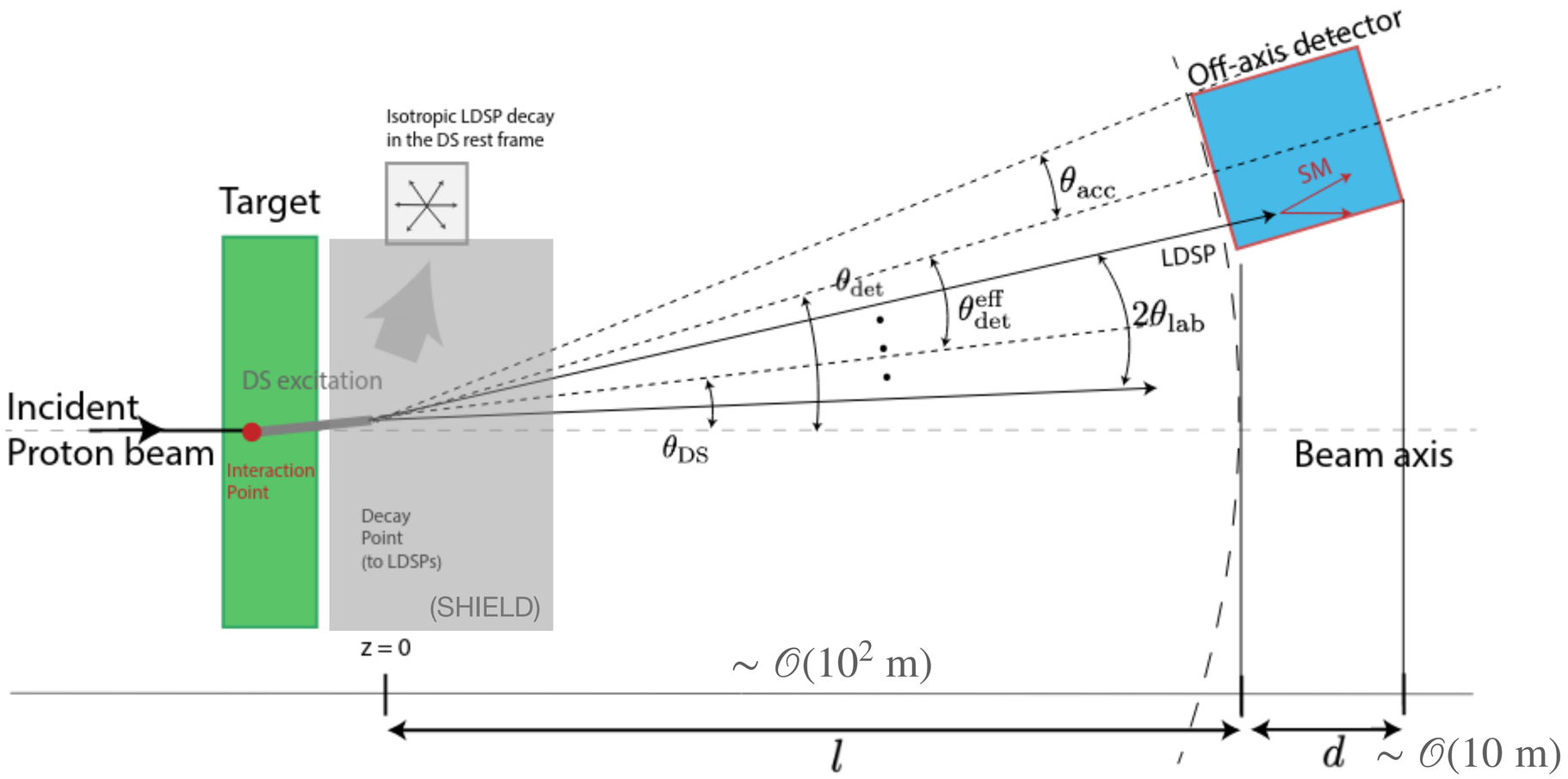
Acceptances not included!

2206.04220

And many more!

Great potential for repurposing/parasiting runs!

Beam dump & ν experiments



Detector can be on-axis

Beam dumps have a shield after target

Renormalizable portal models

$$\epsilon F'_{\mu\nu} B^{\mu\nu}$$

$$\kappa S H^\dagger H \quad y L H N$$

Renormalizable portal models

$\epsilon F'_{\mu\nu} B^{\mu\nu}$

The dark photon $F_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu$

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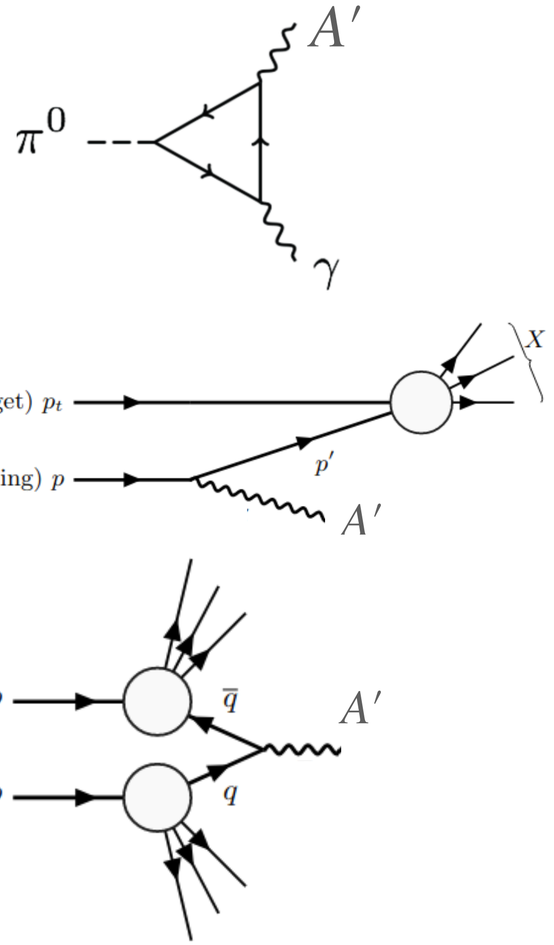

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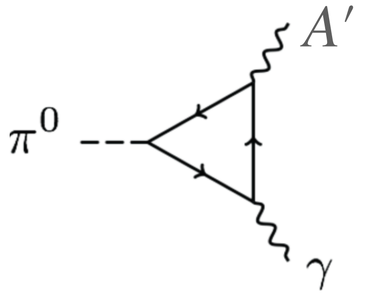
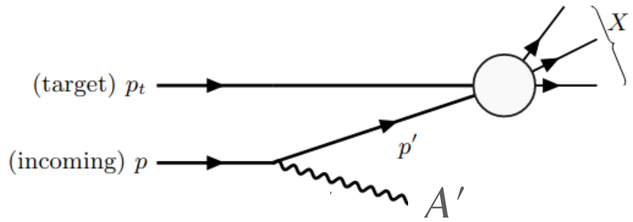
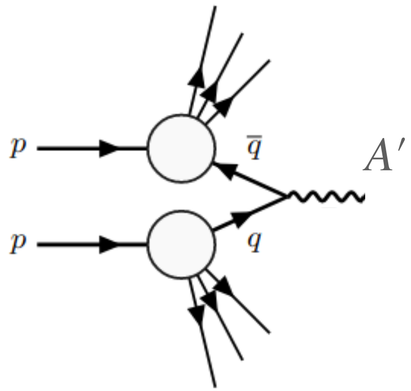






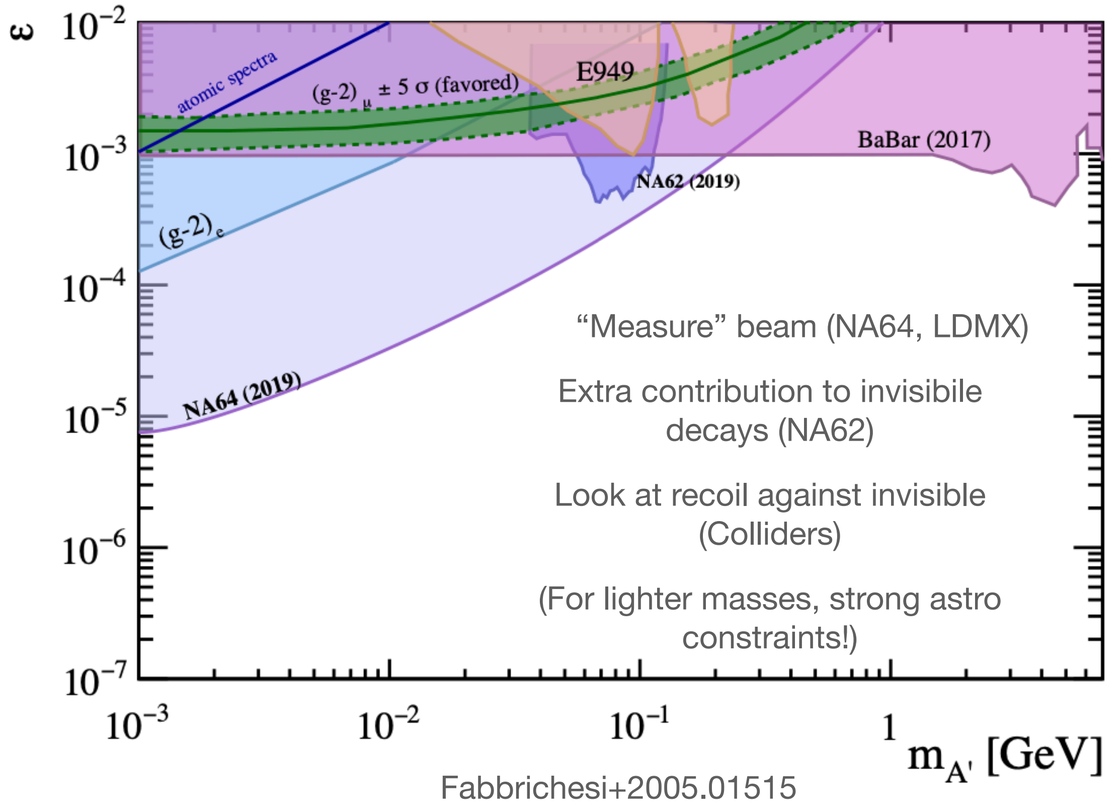
Dark photon is coupled to DM particle χ:
$A'_\mu(\bar{\chi}\gamma^\mu\chi)$

Typically mass relation fixed to
$m'_A \sim 3m_\chi$

A' typically produced on-shell, then decays into SM or χ

Dark photon portal results

Invisibly decaying Dark Photon



Fabbrichesi+2005.01515

Mass shell of MET or decay products is peaked at m'_A

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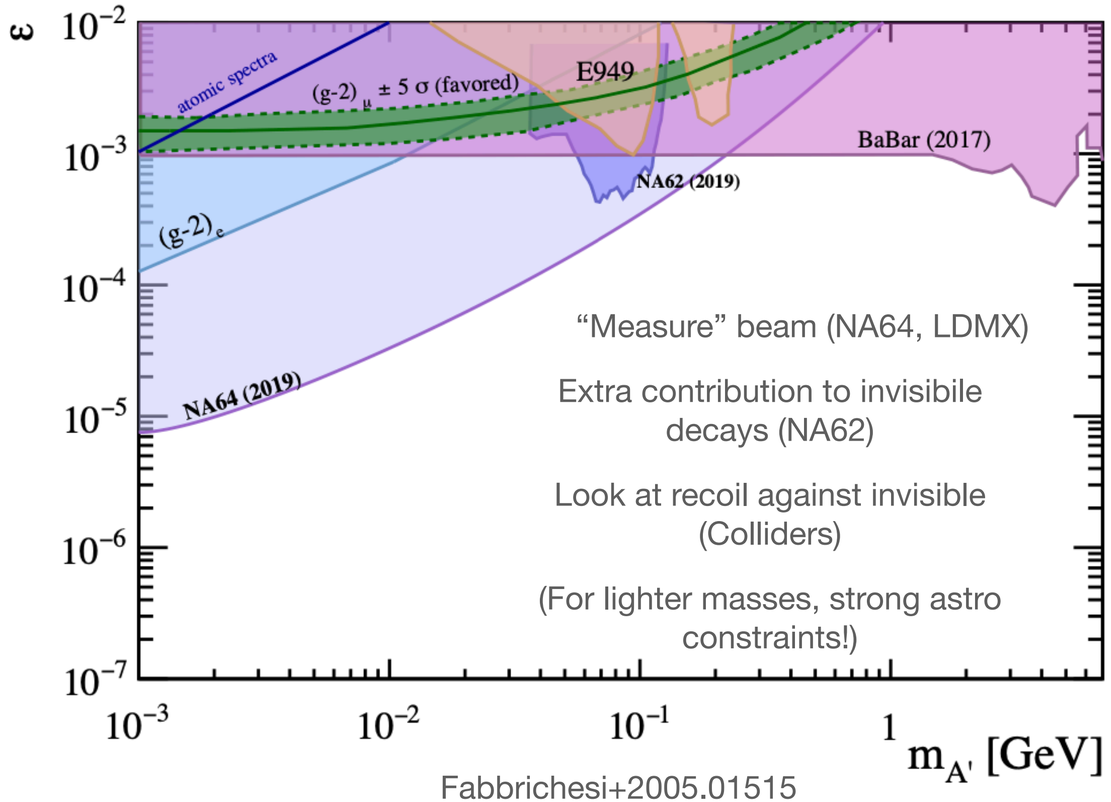
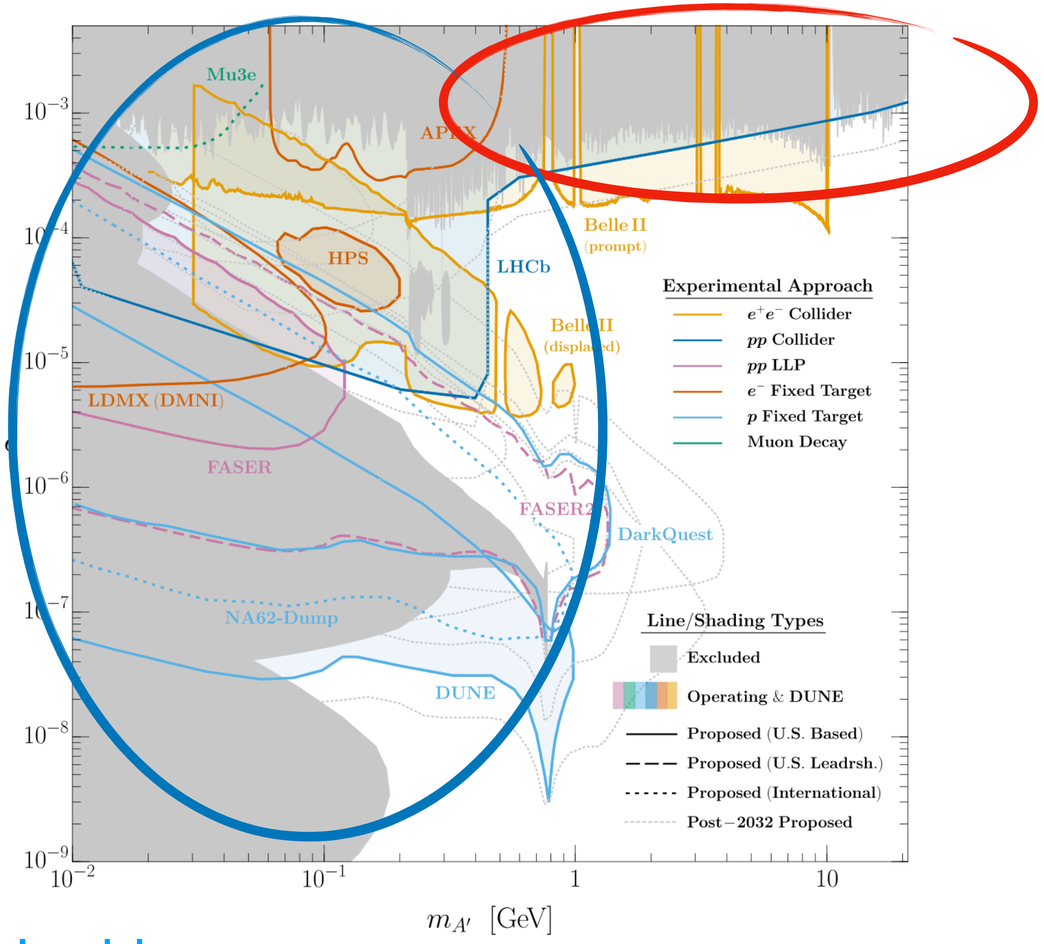


Fabbrichesi+2005.01515

Mass shell of MET or decay products is peaked at m'_A

Prompt decays

Visibly decaying Dark Photon



Displaced decays

Batell+2207.06905

Non-renormalizable portals

Non-renormalizable

$$g_{a\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$\frac{c_O}{\Lambda_{\rm UV}^{\Delta-2}} \mathcal{O}_{\rm DS} H^\dagger H$$

$$\frac{c_J}{\Lambda_{\rm UV}^2} J_{\mu,{\rm DS}} J^\mu_{\rm SM}$$

$$\frac{c_N}{\Lambda_{\rm UV}^{\Delta-5/2}} L H \mathcal{N}_{\rm DS}$$

Non-renormalizable portals

Darme+2001.01490
Cheng+2110.10691
Bertuzzo+2011.04735

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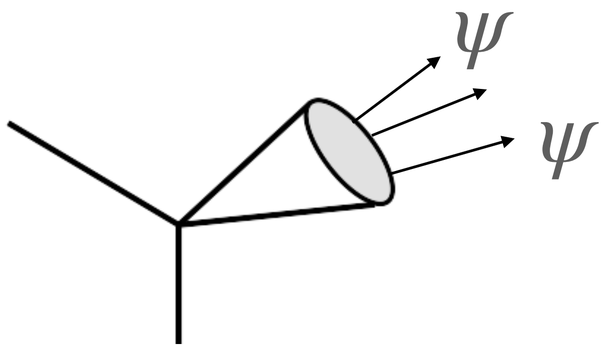
$\Lambda_{\rm UV}$ heavy mediator scale: cannot be produced on-shell!

DS operator generically excites multiparticle state! (Controlled by Δ)



$$\mathcal{O}_{\rm DS}|0\rangle \sim |{\rm DS}\rangle \sim \psi\psi\ldots$$

ψ lightest DS particle.
Not necessarily DM!

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Darme+2001.01490
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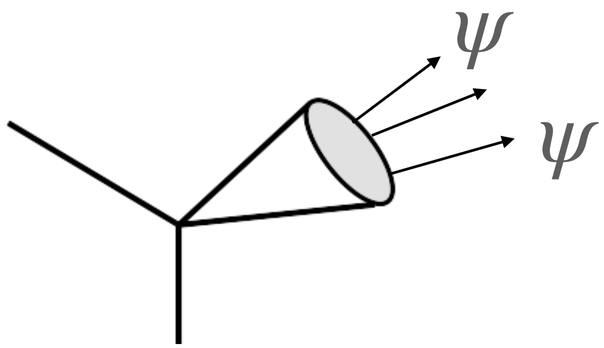

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ψ lightest DS particle.
Not necessarily DM!

Can be **weakly coupled**: LDSP ψ directly excited by DS operator. Like SM ν in neutral current!

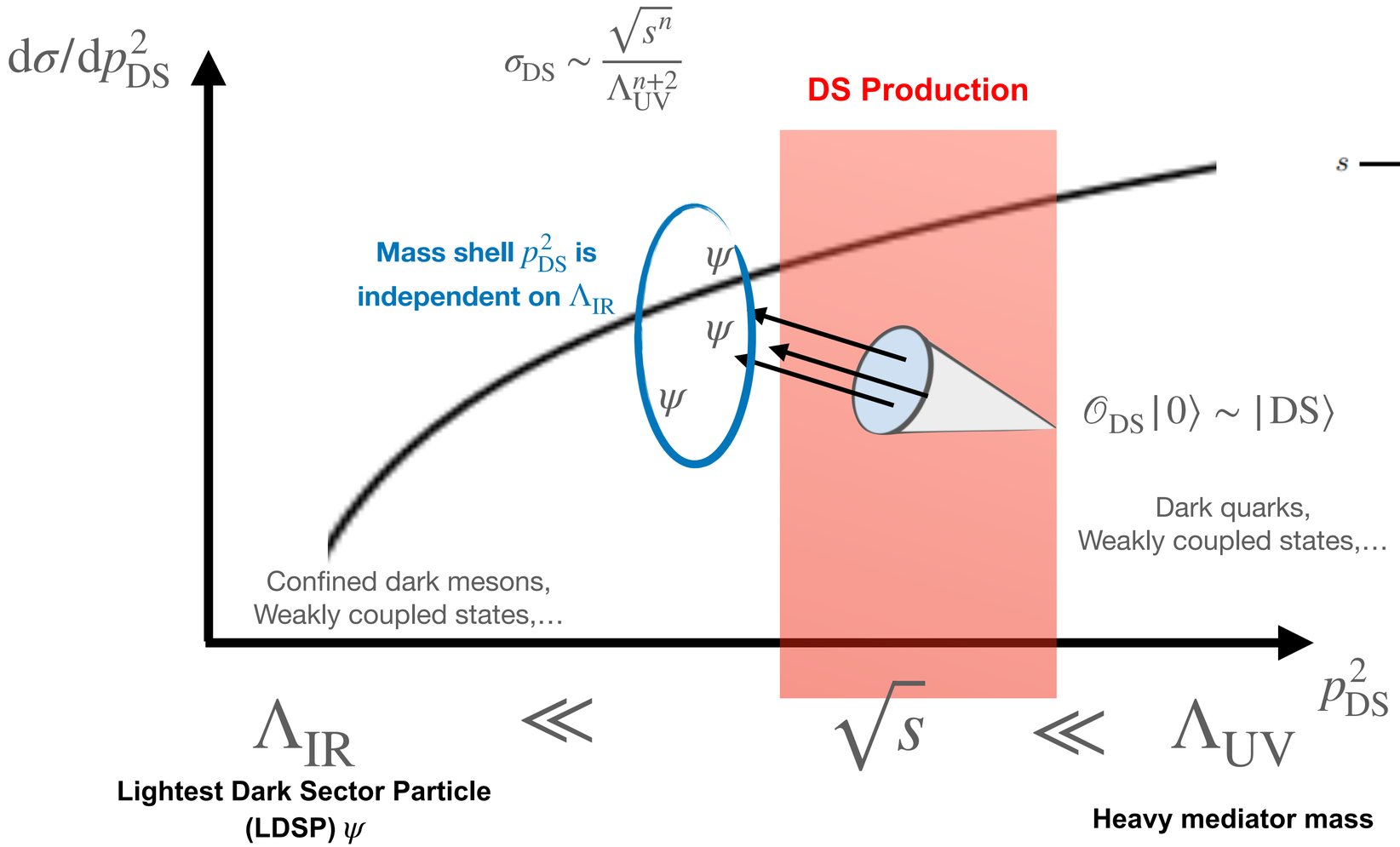
$$\frac{g_{\rm EW}^2}{M_Z^2} \bar{p}p\ \bar{\nu}\nu$$

Can be **strongly coupled**: LDSP ψ comes from DS confinement

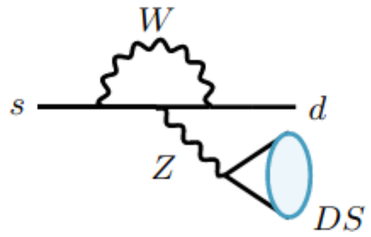
Cosmology depends on these details!
We will not talk about it!

Common in BSM scenarios such as Hidden Valley, Neutral Naturalness, mirror worlds…

Anatomy of non-reno portals

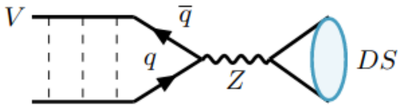


Meson decays



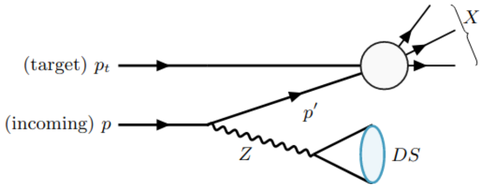
$K \to \pi + \mathrm{DS}$

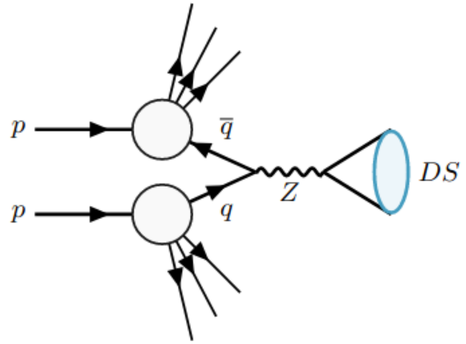
$B \to K + \mathrm{DS}$



$\phi \to \mathrm{DS}$

Bremsstrahlung and Drell-Yan





Missing energy

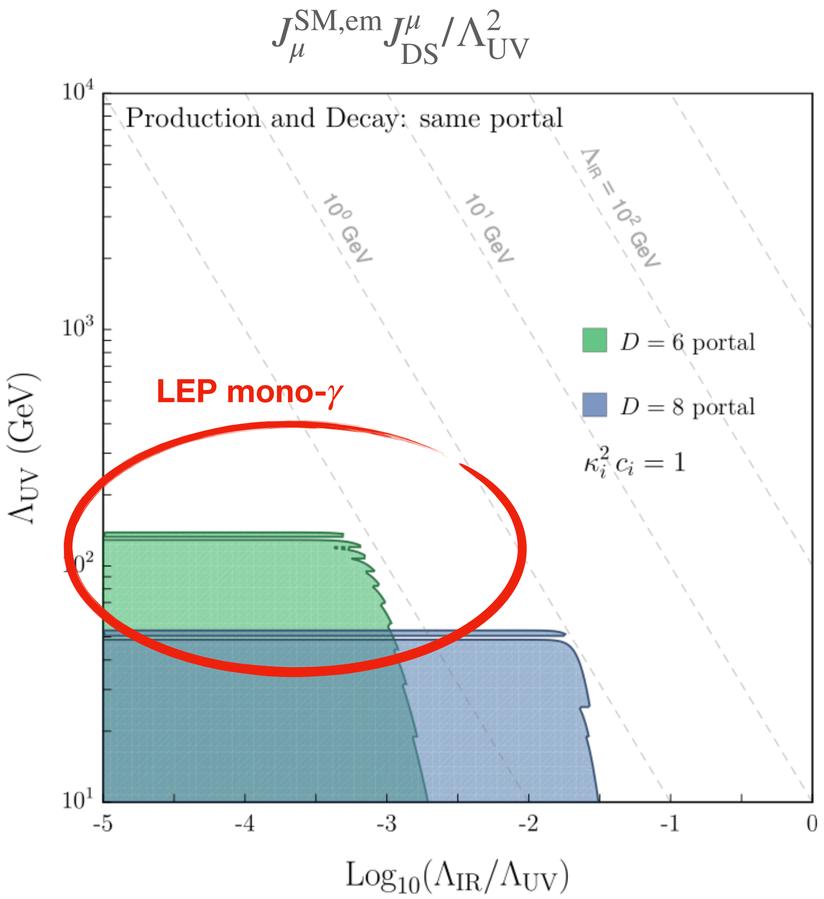
Contino+2012.08537

$$S \sim \mathscr{L}\sigma_{\rm DS}$$

$$\sigma_{\rm DS} \propto \sum_{\rm DS} |\langle {\rm DS}|\mathcal{O}_{\rm DS}|0\rangle|^2 \sim \sqrt{s^n}$$

Model independent: inclusive $\sigma_{\rm DS}$! Only ask for ψ to not decay

Missing energy mass shell
$p^2_{\rm DS} \neq \Lambda^2_{\rm IR}$



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Missing energy mass shell
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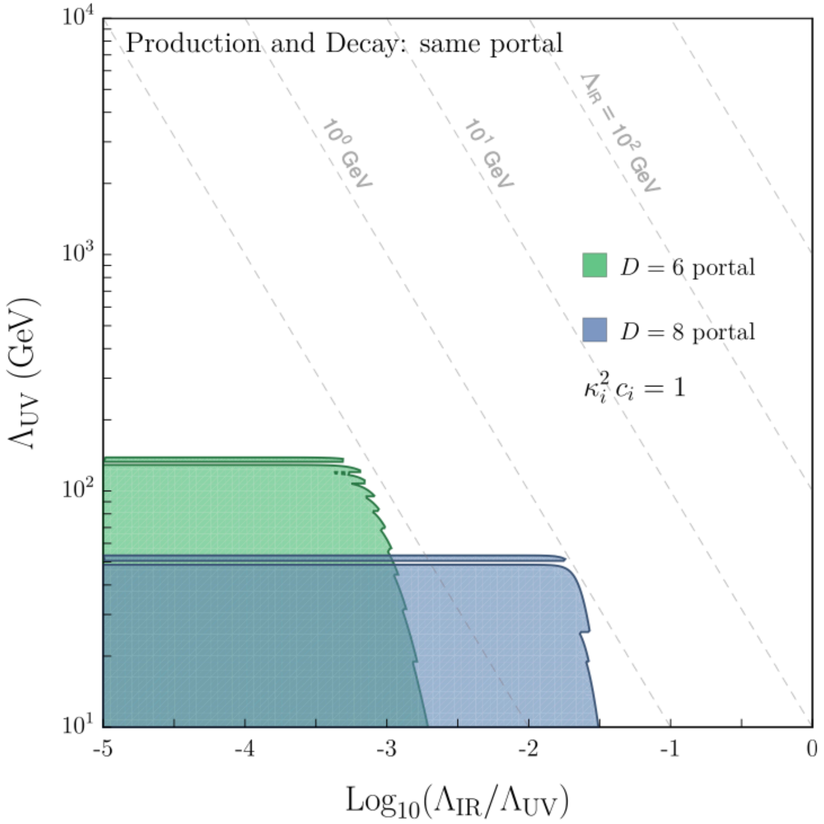
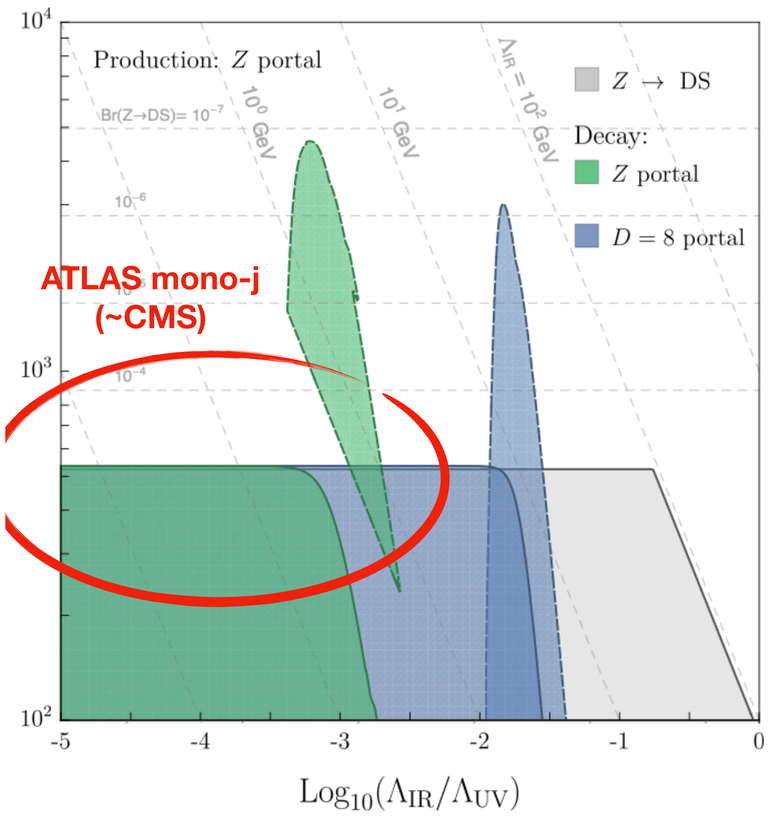
$J^{\rm SM,em}_\mu J^\mu_{\rm DS}/\Lambda^2_{\rm UV}$



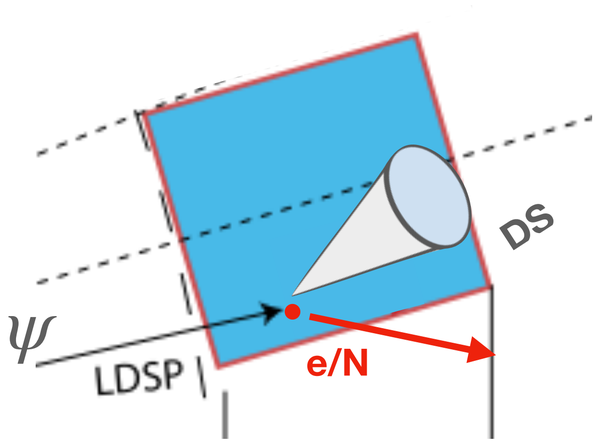
$p^2_{\rm DS} \sim \sqrt{s}$

$H^\dagger \partial_\mu H J^\mu_{\rm DS}/\Lambda^2_{\rm UV}$



$p^2_{\rm DS} \sim m^2_Z$

Scattering/disintegration



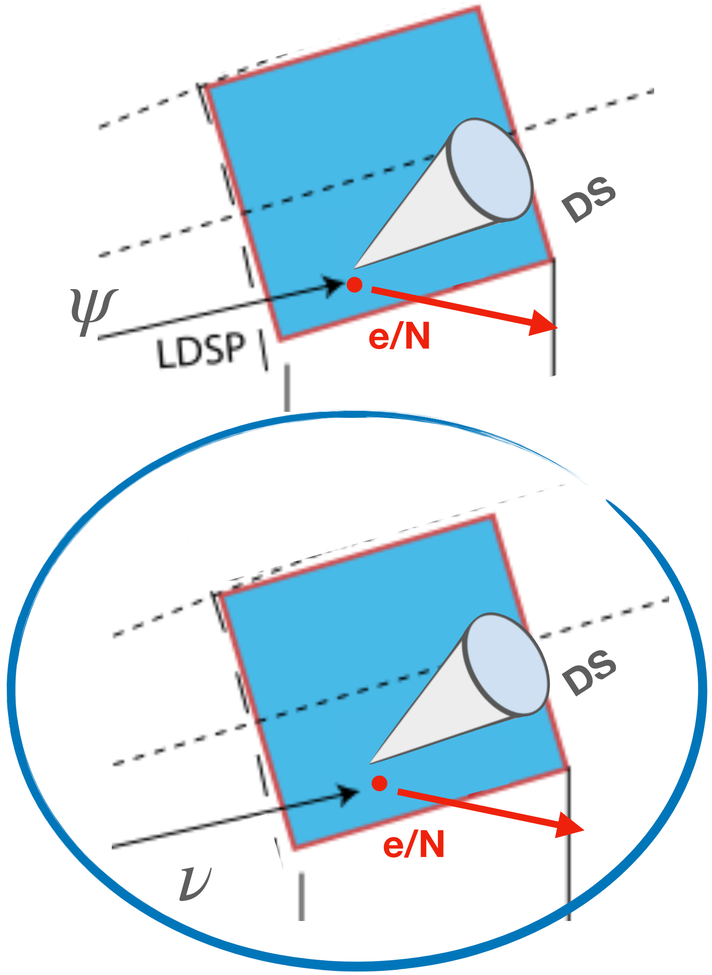
i) ψ stable: reaches detector and disintegrates against SM particles

SM recoils is different from scattering against light, single particle ν DIS

Unique opportunity for ν detectors!

DUNE, Faserν, SHiP,…

Scattering/disintegration



i) ψ stable: reaches detector and disintegrates against SM particles

SM recoils is different from scattering against light, single particle ν DIS

Unique opportunity for ν detectors!

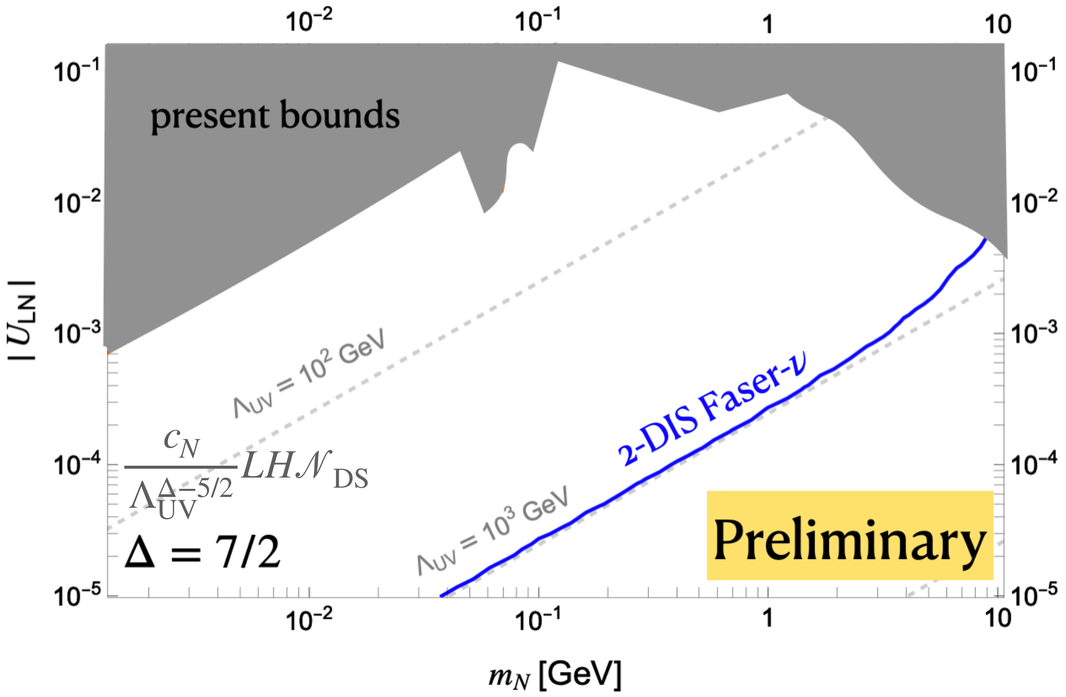
DUNE, Faserν, SHiP,…

ii) ν disintegrates into ψ: INCLUSIVE and model independent!

$$\sum_{\mathrm{DS}} |\langle \mathrm{DS}|\mathcal{O}_{\mathrm{DS}}|0\rangle|^2$$

Borrello MC Redigolo (WIP)

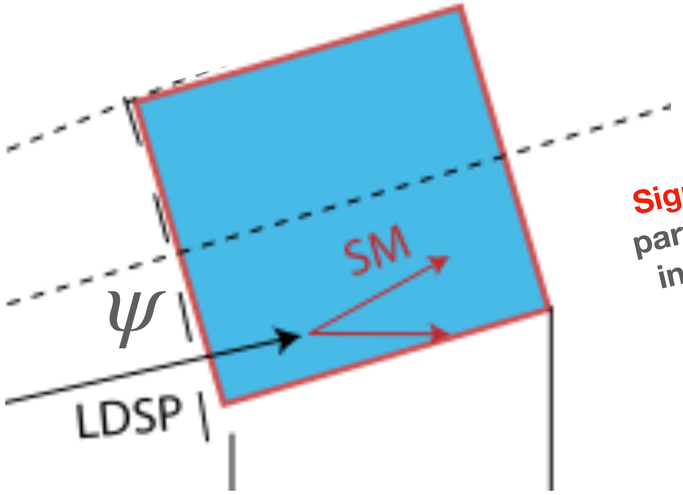
ν disintegration against protons



Need kinematic cuts to improve bkg rejection!

Displaced vertex

MC Mishra Verma 2211.13253

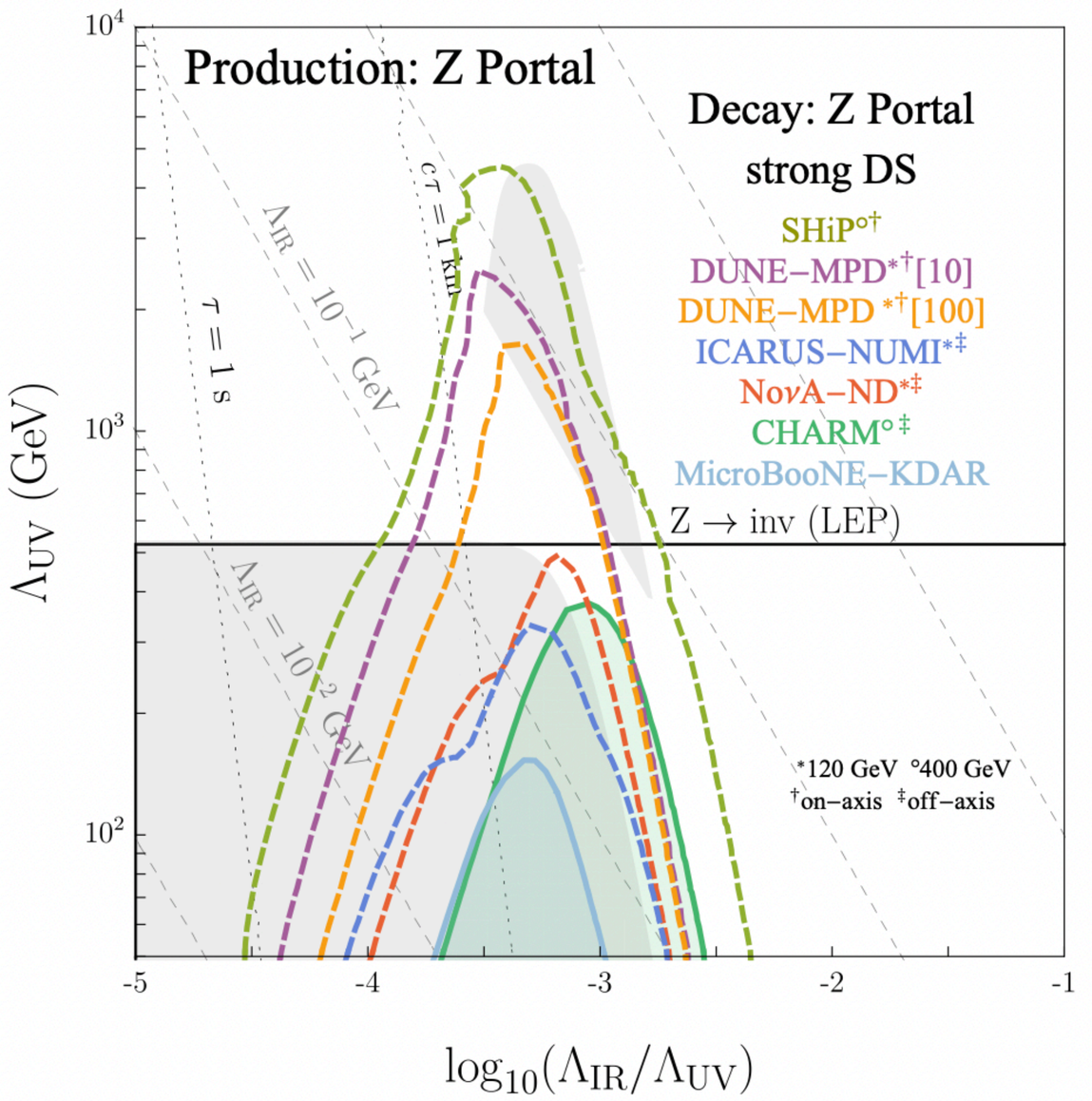


Signature: visible particles decaying in "far" detector

Depends on ψ lifetime

$$\langle 0 \,|\, \mathcal{O}_{\rm DS} \,|\, \psi \rangle \sim \Lambda_{\rm IR}^{\Delta-1}/4\pi$$

$$S \sim \frac{N_{\rm POT}}{\sigma_{pN}} \times \sigma_{\rm DS} \times P_{\rm dec} \times \epsilon_{\rm geo}$$



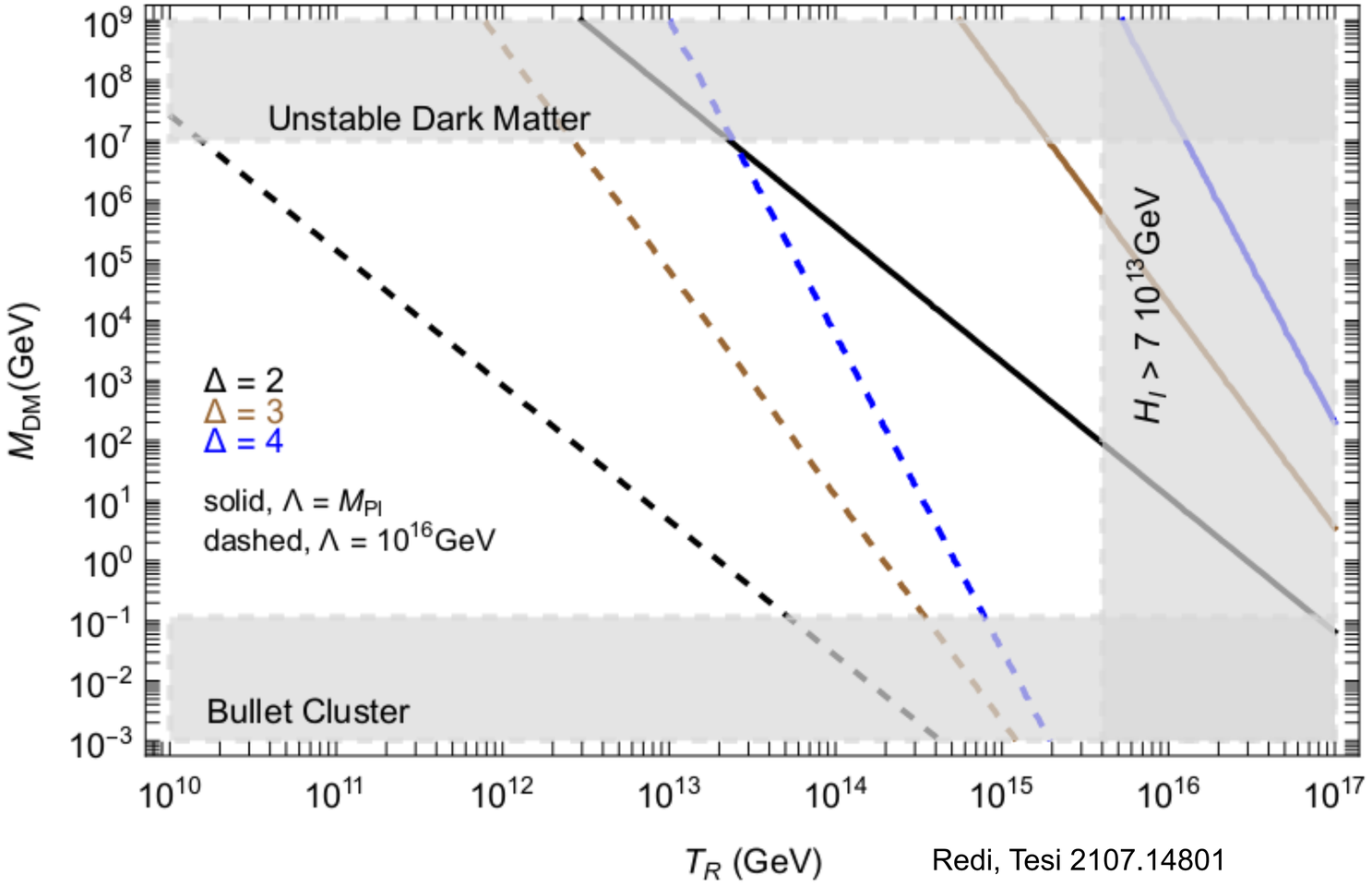
Conclusions

- SM-DS portal interactions well motivated possibility.
- Typical scales: $\Lambda_{\rm IR} \sim {\rm MeV} \div {\rm GeV}$
- Non-renormalizable portals: not unusual in BSM scenarios. Can be seen as exciting multi-particle dark states
- Missing energy, disintegration signatures at future experiments have distinct kinematical signature controlled by Δ.
- Displaced decays, prompt more similar to standard case
- Probing up to $\Lambda_{\rm UV} \sim {\rm TeV}$.

Thanks for the attention!

Backup

Cosmology



Redi, Tesi 2107.14801

Redi, Tesi 2107.14801
Hong, Kurup, Perelstein 1910.10160

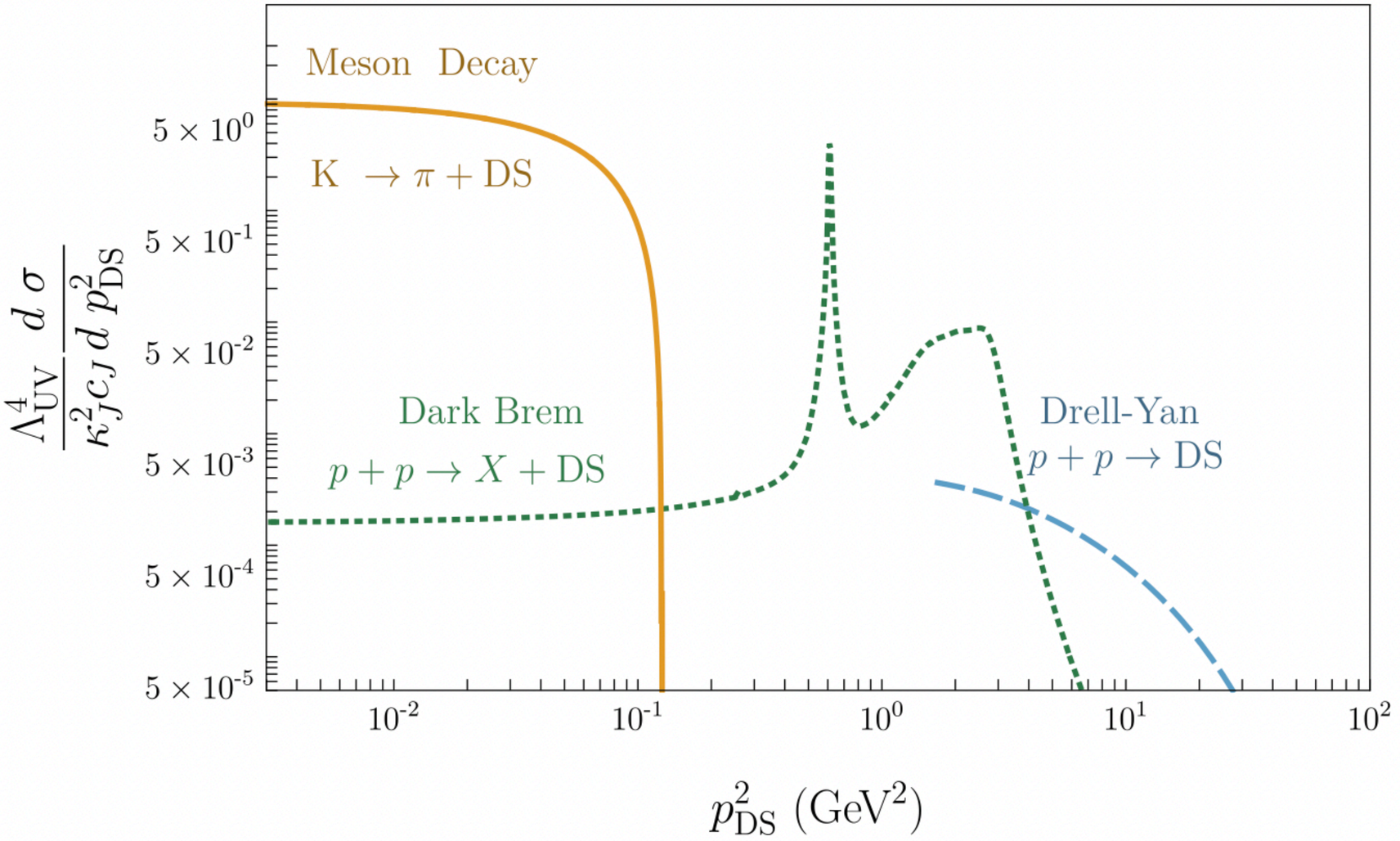
Freeze-in is a possibility
(although for very high cutoffs in model indep. scenario)

$$f_L H f_R \to CFT$$

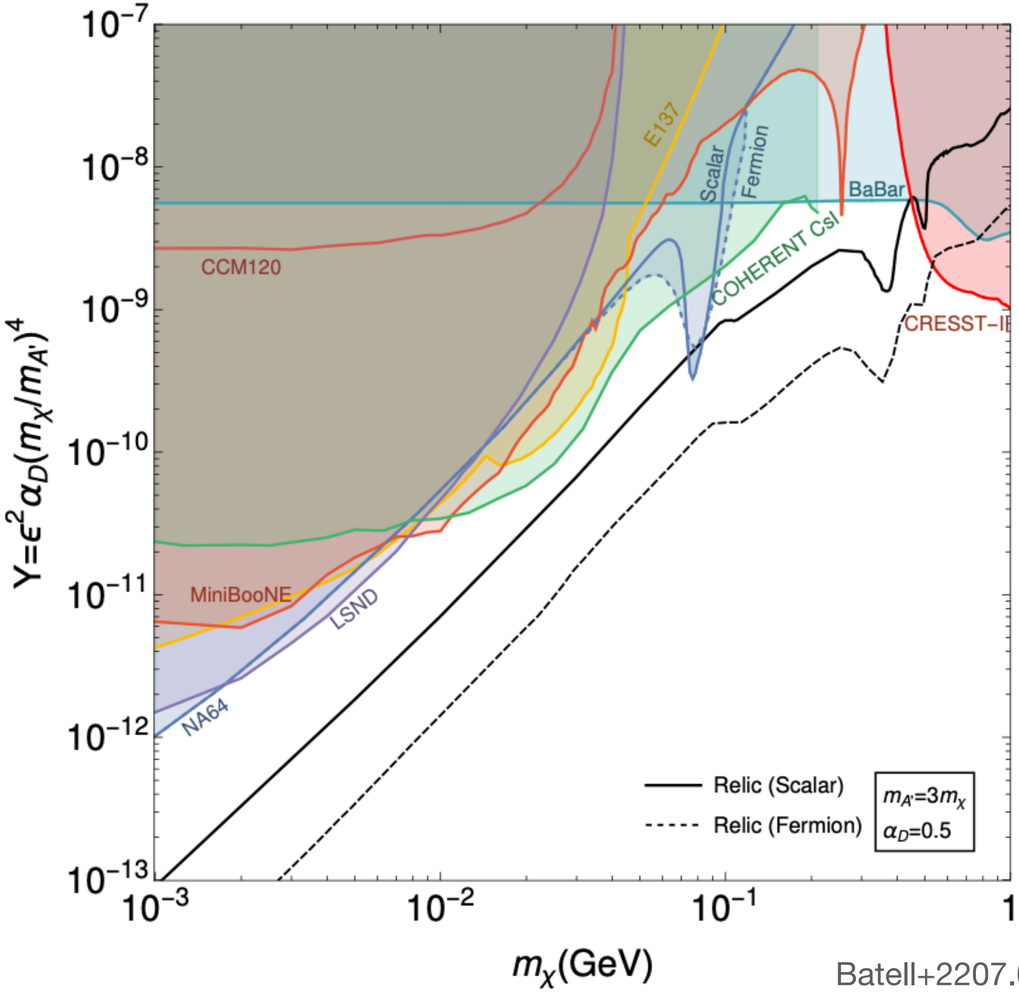
Specifics

Experiment	N_{POT} (total)	E_{beam} (GeV)	l (m)	d (m)	Off-axis angle, θ_{det} (rad)	θ_{acc} (rad)
CHARM [78, 85, 86]	2.4×10^{18}	400	480	35	0.01	0.003
NOνA-ND [47, 84]	3×10^{20}	120	990	14.3	0.015	0.002
MicroBooNE (KDAR) [81]	1.93×10^{20}	120	100	10.4	-	0.013
ICARUS-NuMI [11, 16]	3×10^{21}	120	803	19.6	0.097	0.005
DUNE-MPD[14, 87]	1.47×10^{22}	120	579	5	0	0.004
SHiP [65, 77]	2×10^{20}	400	64	50	0	0.078

Production cross-section



Dark Photon-DM constraints



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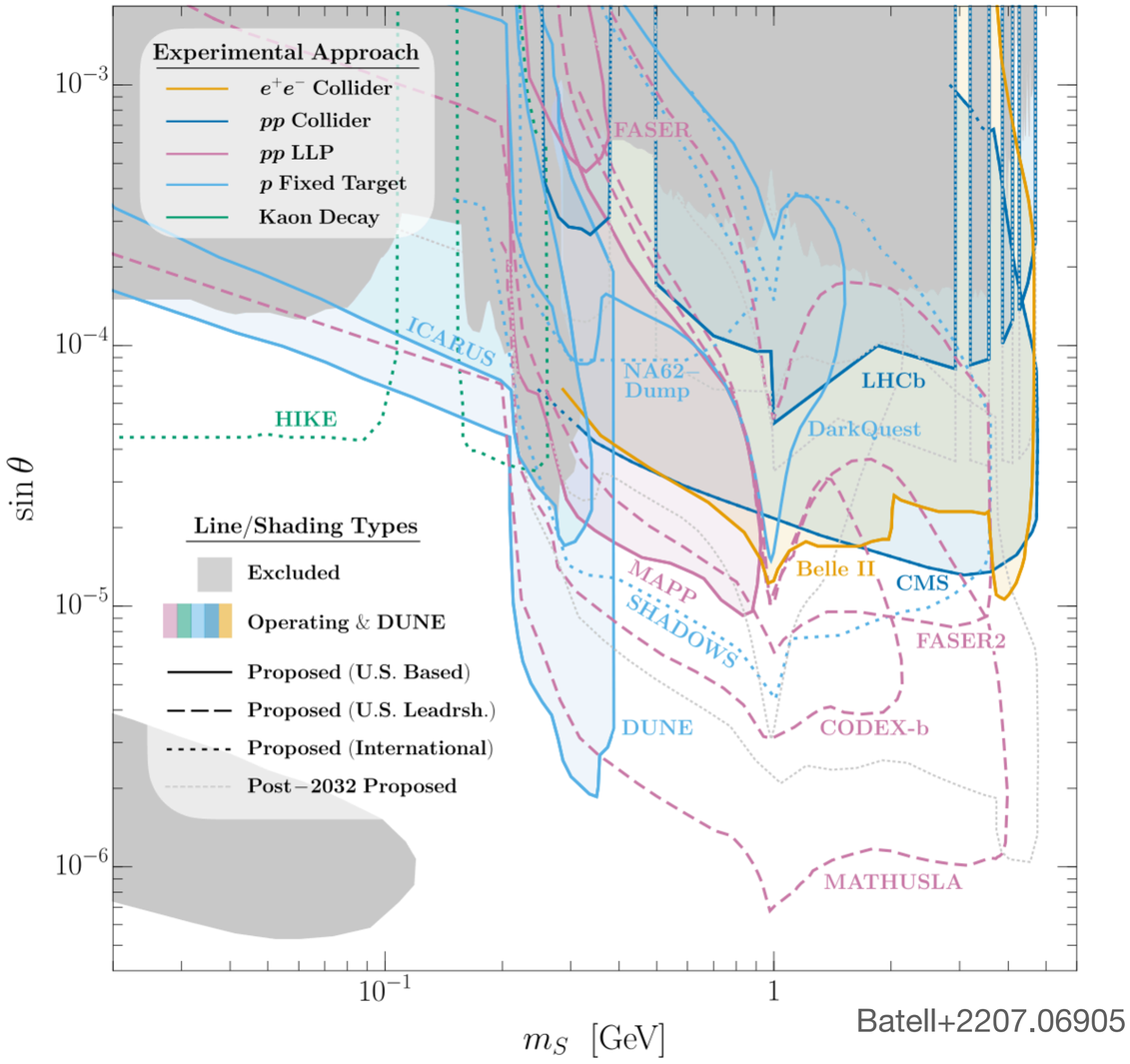
Dark photon produced on-shell

Dark photon decays into $\chi, \bar{\chi}$

χ scatters against detectors

Scalar portal



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