Model independent bounds for elusive DS at ν experiments

(and other high intensity exp.)

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based on WIP

In collaboration with Rashmish K. Mishra and Sonali Verma

Which Dark Sector?

$$\mathcal{O}_{\rm DS}\mathcal{O}_{\rm SM}$$

$$SH^\dagger H$$

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

$$H^{c\dagger}\bar{N}l$$

MeV-GeV DM

For High Intensity exp. constraints:

Batell, Pospelov, Ritz 0906.5614
deNiverville, McKeen, Ritz 1205.3499
deNiverville, Chen, Pospelov, Ritz 1609.01770
Buonocuore, Frugiuele, deNiverville 1912.09346
and many many more!

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Contino, Max, Mishra 2012.08537
Darme, Ellis, You 2001.01490
Cheng, Li Salvioni 2110.10691

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

Elusive

$$\frac{k}{\Lambda_{\rm UV}^2}H^\dagger \overleftrightarrow{D_\mu} H\, J^\mu_{\rm DS}$$

$$\frac{k}{\Lambda_{\rm UV}^2}J^{\rm SM}_\mu J^\mu_{\rm DS}$$

Model independent approach

$\Lambda_{\rm IR}$ << $\Lambda_{\rm UV}$

Heavy mediator scale

ψ

$\mathcal{O}_{\rm SM}\mathcal{O}_{\rm DS}$

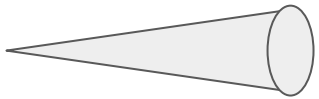
Lightest Dark Sector Particle

Model independent approach

$\Lambda_{\rm IR}$ << $\Lambda_{\rm UV}$ **Heavy mediator scale**

ψ **Conformal regime** $\mathcal{O}_{\rm SM}\mathcal{O}_{\rm DS}$

Lightest Dark Sector Particle

$\mathcal{O}_{\rm DS}|\Omega\rangle =$ 

- weakly coupled states
- dark “gluons”
- …

A ν perspective

- 1956: Cowan-Reines discover ν CC
- 1973: ν NC discovery at Gargamelle
- 1983 : Z discovered

Contino, Max, Mishra 2012.08537

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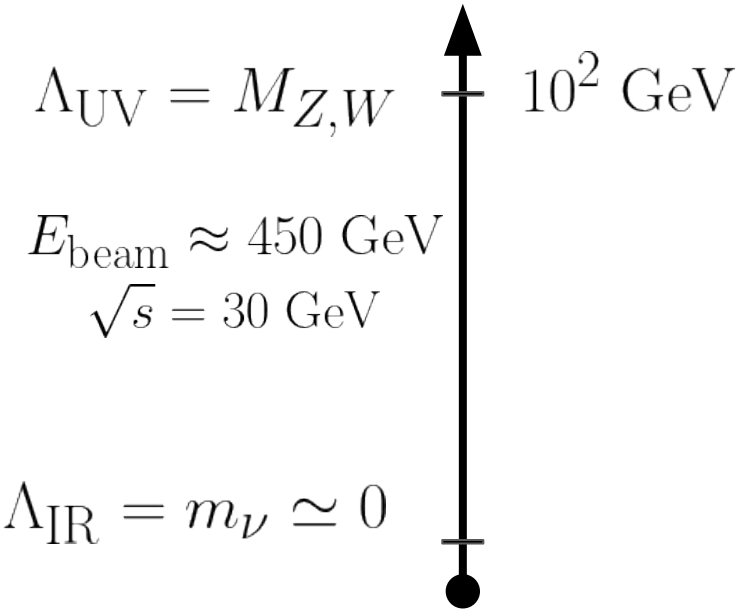

A ν perspective

- 1956: Cowan-Reines discover ν CC
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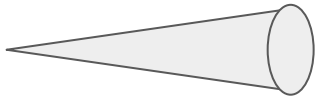
$$\mathcal{O}_{\rm DS} = \bar{\nu}\gamma^\mu P_L \nu \qquad \mathcal{O}_{\rm SM} = J^\mu_{Z,p}$$



$$= \bar{\nu}\nu$$

Contino, Max, Mishra 2012.08537

$$\Lambda_{\rm UV} = M_{Z,W} \quad 10^2 \text{ GeV}$$

$$E_{\rm beam} \approx 450 \text{ GeV}$$

$$\sqrt{s} = 30 \text{ GeV}$$

$$\Lambda_{\rm IR} = m_\nu \simeq 0$$

Bounding the models: production

Contino, Max, Mishra 2012.08537

Inclusive Production

$$\sigma \propto \int \mathrm{d}\Phi_{\mathrm{DS}} \sum_n |\langle \mathrm{DS}|\mathcal{O}_{\mathrm{DS}}|\Omega\rangle|^2 = 2i\ \mathrm{Im}\left[\langle\Omega|\mathcal{O}_{\mathrm{DS}}\mathcal{O}_{\mathrm{DS}}|\Omega\rangle\right]$$

DS "internal phase space" at fixed p_{DS}

optical theorem

Bounding the models: production

Contino, Max, Mishra 2012.08537

Inclusive Production ⟹ **Model independent**

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optical theorem

DS "internal phase space" at fixed p_{DS}

$c_{\mathcal{O}} p_{\mathrm{DS}}^{2\Delta}$ **Conformality**

Rest: fixed by $\mathcal{O}_{\mathrm{SM}}$:

Integrate p_{DS}

Bounding the models: detection

Contino, Max, Mishra 2012.08537

Detection: depend on ψ properties

Decay

$$\langle \psi | \mathcal{O}_{\rm DS} | \Omega \rangle \sim f \Lambda_{\rm IR}^{\Delta - 2}$$

$$f \sim c_{\mathcal{O}} \Lambda_{\rm IR} / 4\pi$$

portal **fixed** by spin

BR **inherited** by $\mathcal{O}_{\rm SM}$

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Contino, Max, Mishra 2012.08537

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Scatter

$$\langle \psi_j(p_f) | \mathcal{O}_{\rm DS} | \psi_i(q_i) \rangle$$

Scattering depend on splittings, extra form factors,...

Bounding the models

Contino, Max, Mishra 2012.08537

short $c\tau$

- Prompt decays
- Displaced Vertex @ LHC
- Beam dumps (E137)
- Missing energy @ LEP/LHC
- Z/H invisible width
- Missing energy (NA64)
- Rare hadron decays (BESSIII, BaBar, ...)

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Contino, Max, Mishra 2012.08537

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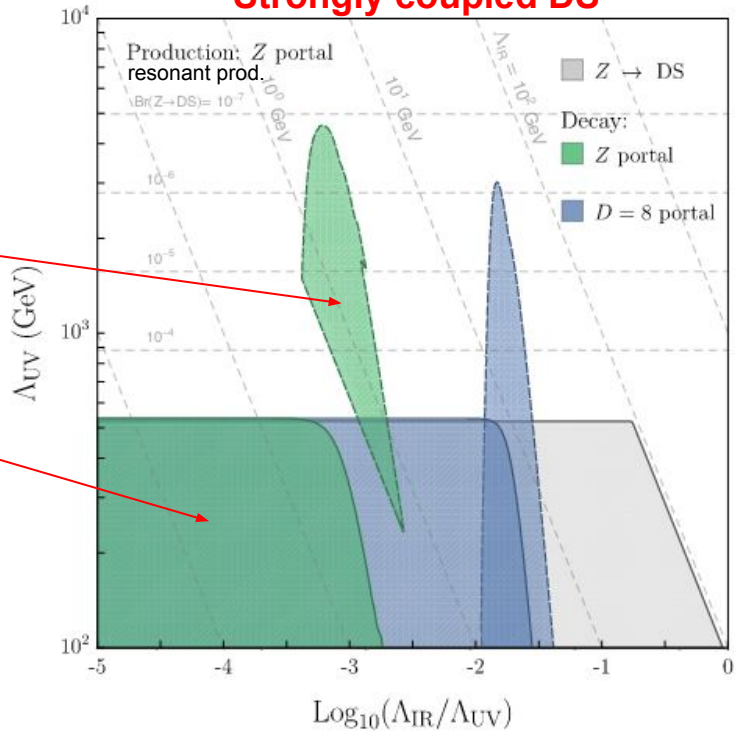
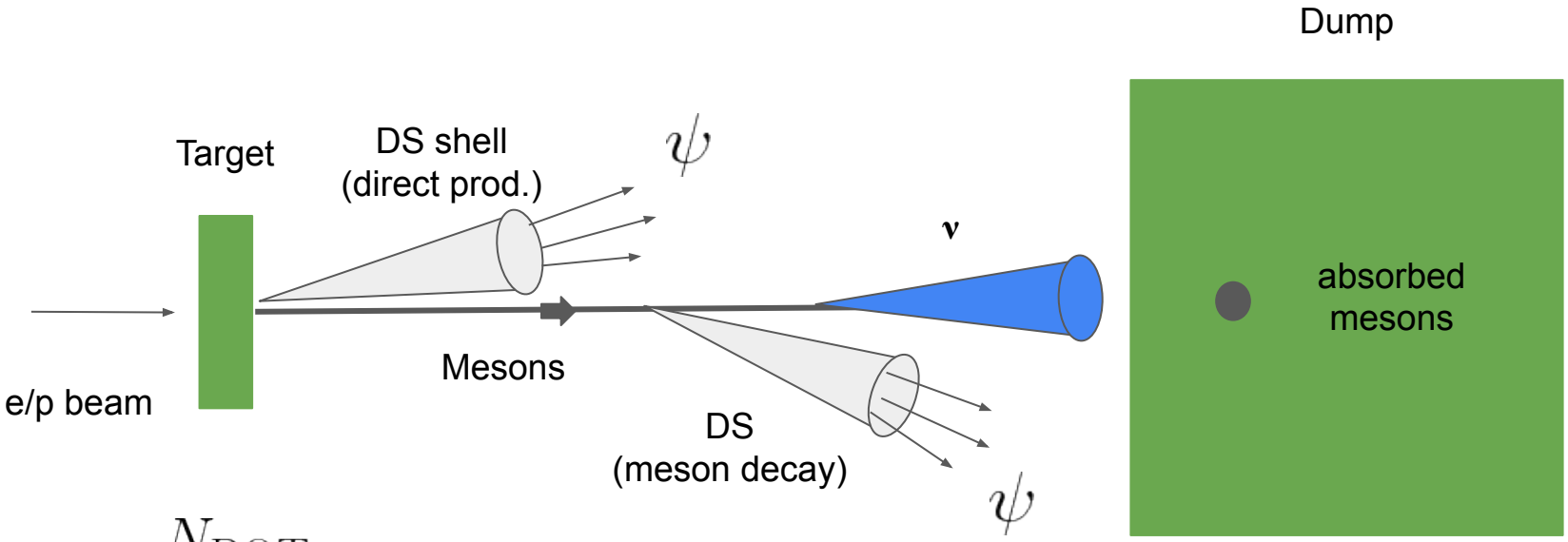
Strongly coupled DS

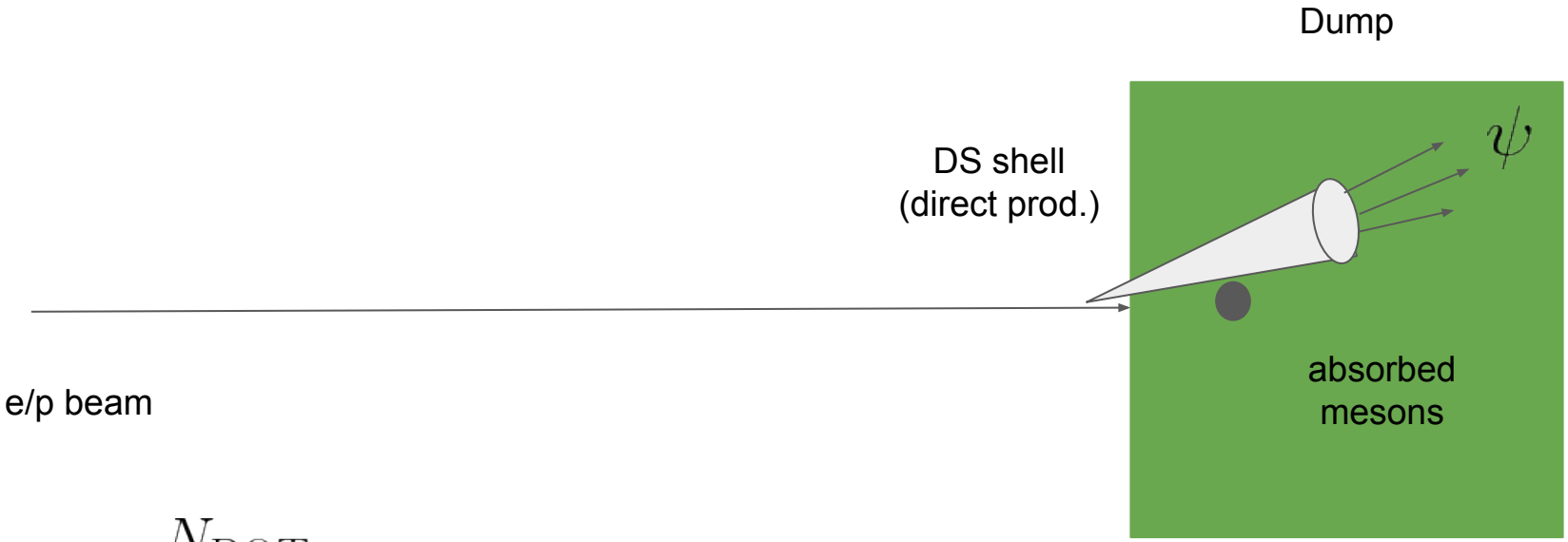


High intensity experiments



$$S \simeq \frac{N_{\mathrm{POT}}}{\sigma_{pN}} \times \sigma_{\mathrm{DS}}$$

High intensity experiments



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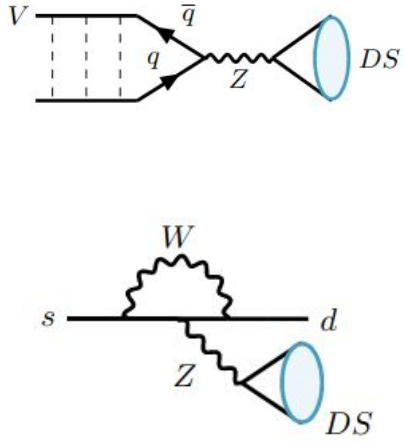
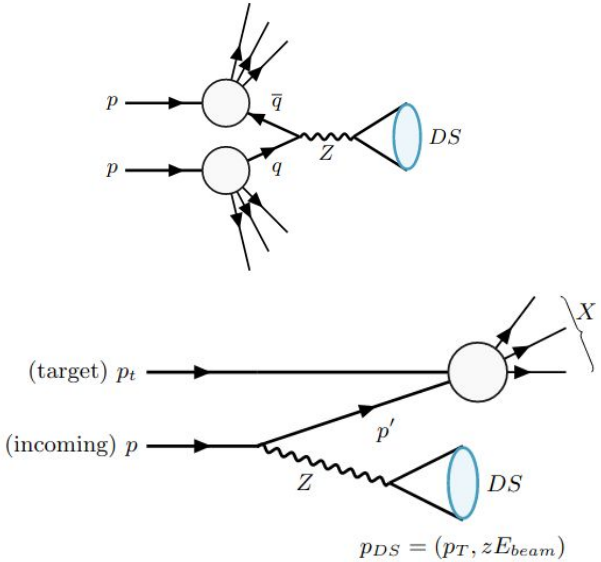
Production modes at ν experiments

Meson decay

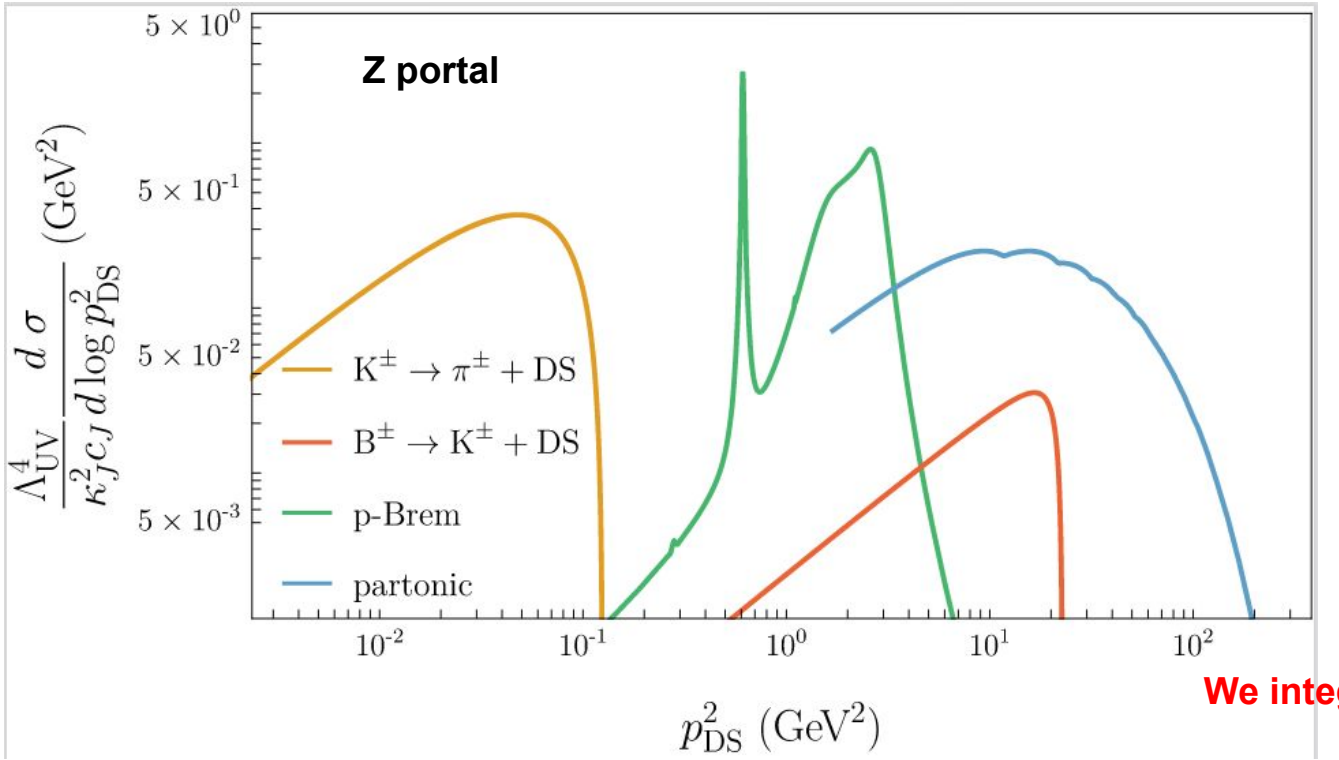


“Direct” production



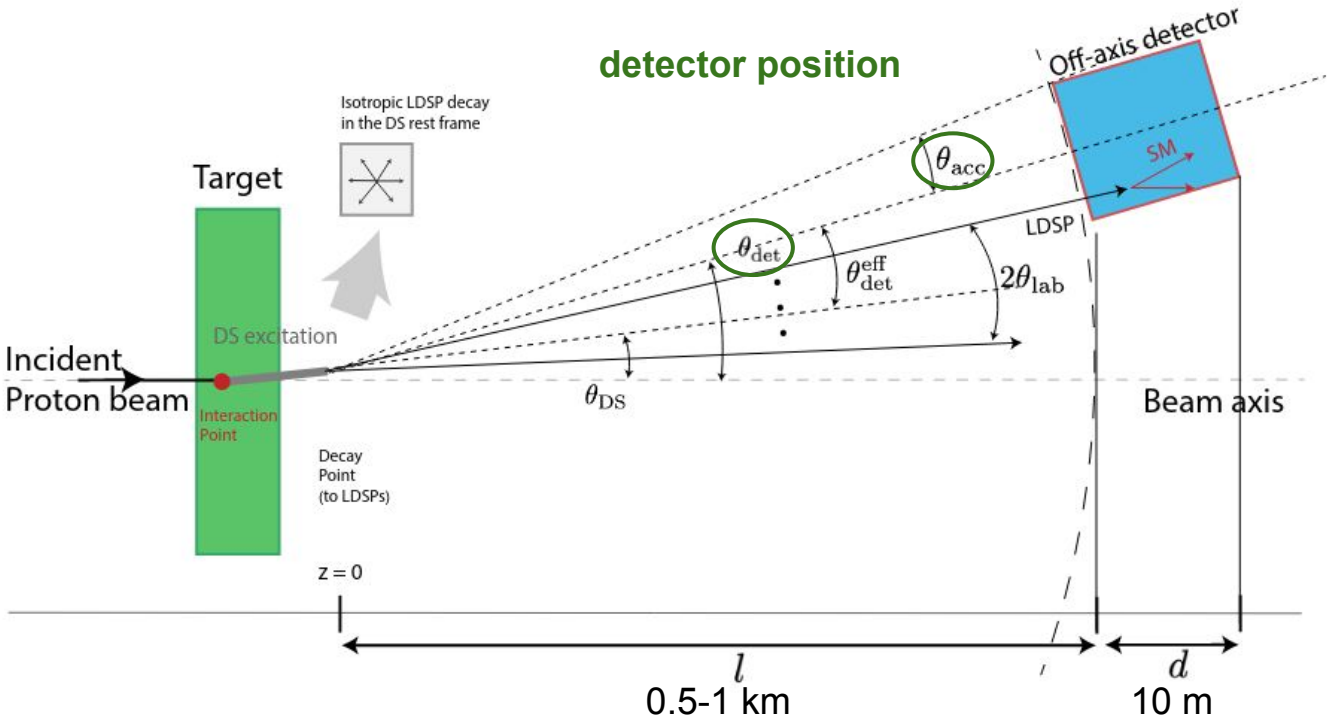
(true for proton beam dumps in general, except for meson production)

Production modes at ν experiments



We integrate over $p_{\rm DS}$

Detection at ν experiments



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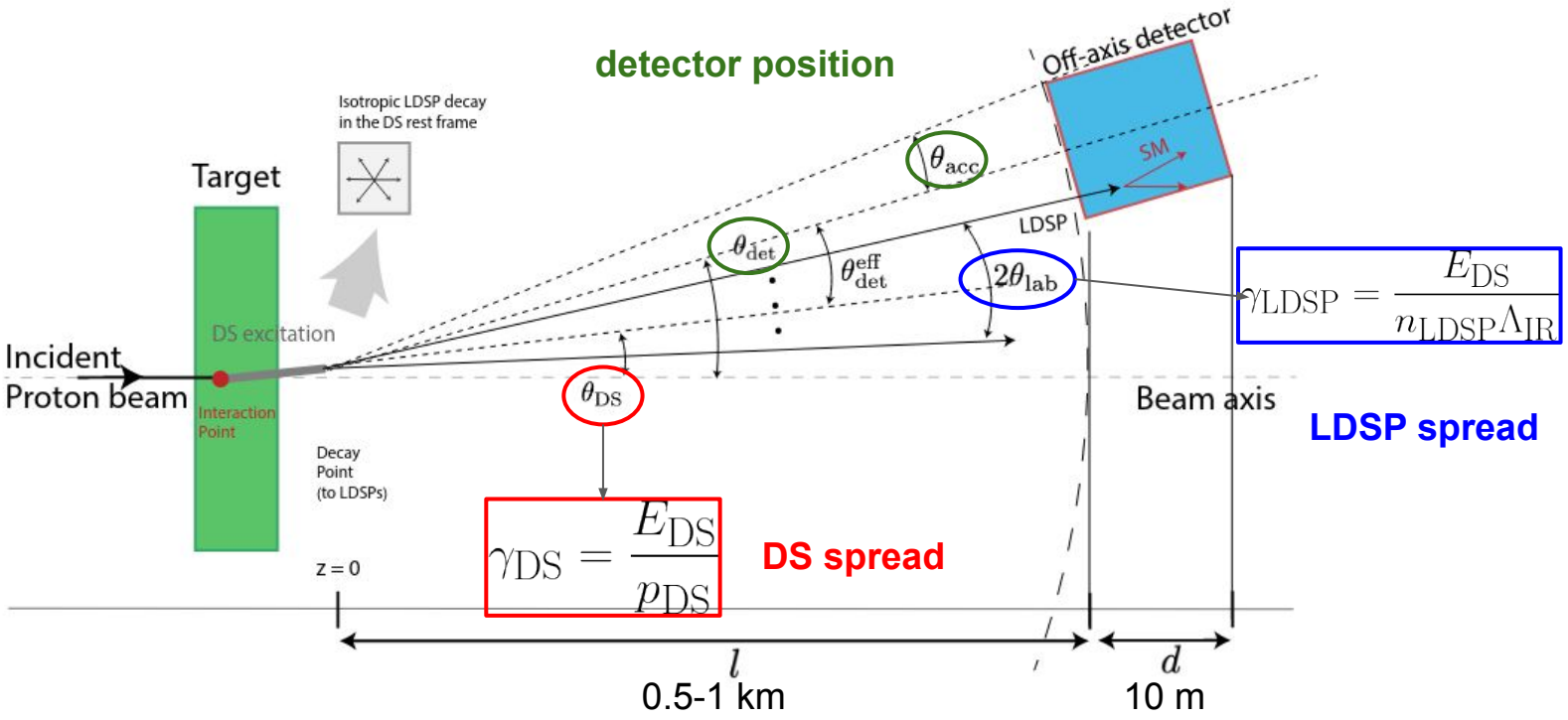

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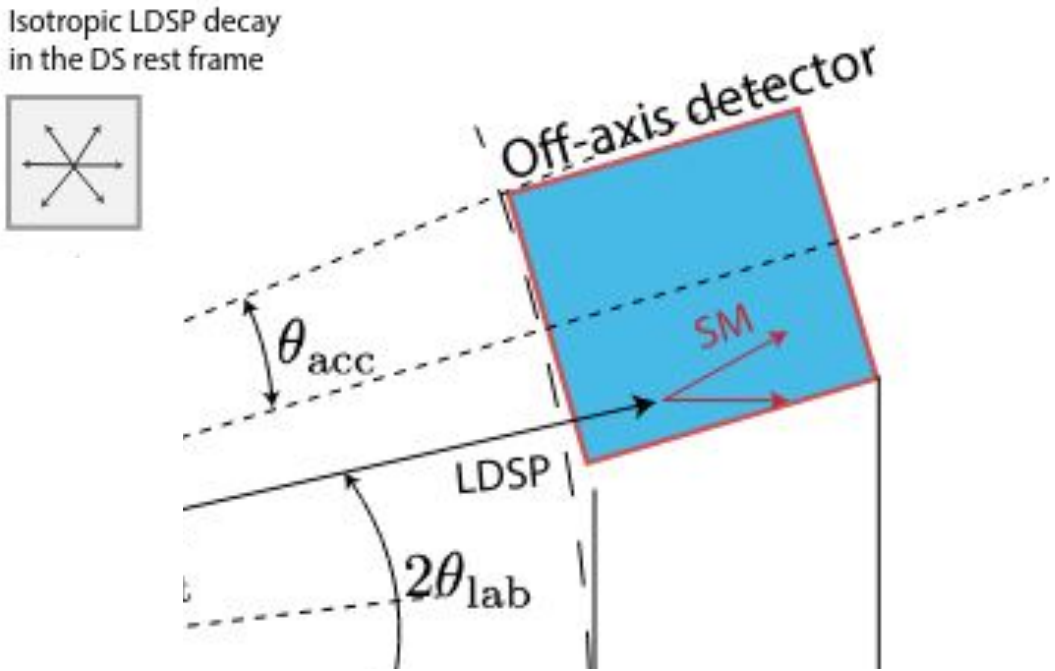


Signature:
two separated e+e- showers
or
single very energetic
electron signature

(Reducible) backgrounds:
NCQE pi0->
misreconstructed photons
or
CC events
under control!

Batell, Berger, Ismail 1909.11670
Foroughi-Abari, Ritz 2004.14515
Berryman, de Gouvea, Fox, Kayser, Kelly, Raaf 1912.07622
and others

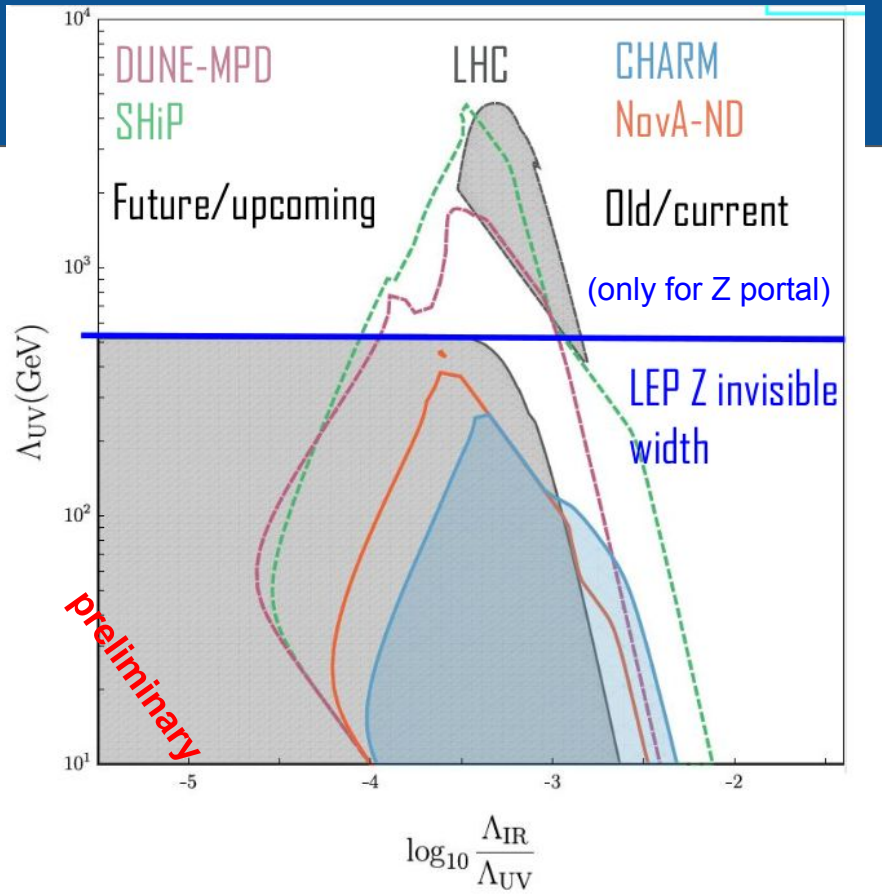
Results

Strongly coupled

10 events line

$$\frac{k}{\Lambda_{\rm UV}^2} H^\dagger \overleftrightarrow{D_\mu} H J^\mu_{\rm DS} \quad \text{ɔ} \quad v m_Z Z_\mu J^\mu_{\rm DS}$$

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



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$$\frac{k}{\Lambda_{\rm UV}^2} H^\dagger \overleftrightarrow{D_\mu} H J^\mu_{\rm DS} \quad \supset \quad v m_Z Z_\mu J^\mu_{\rm DS}$$

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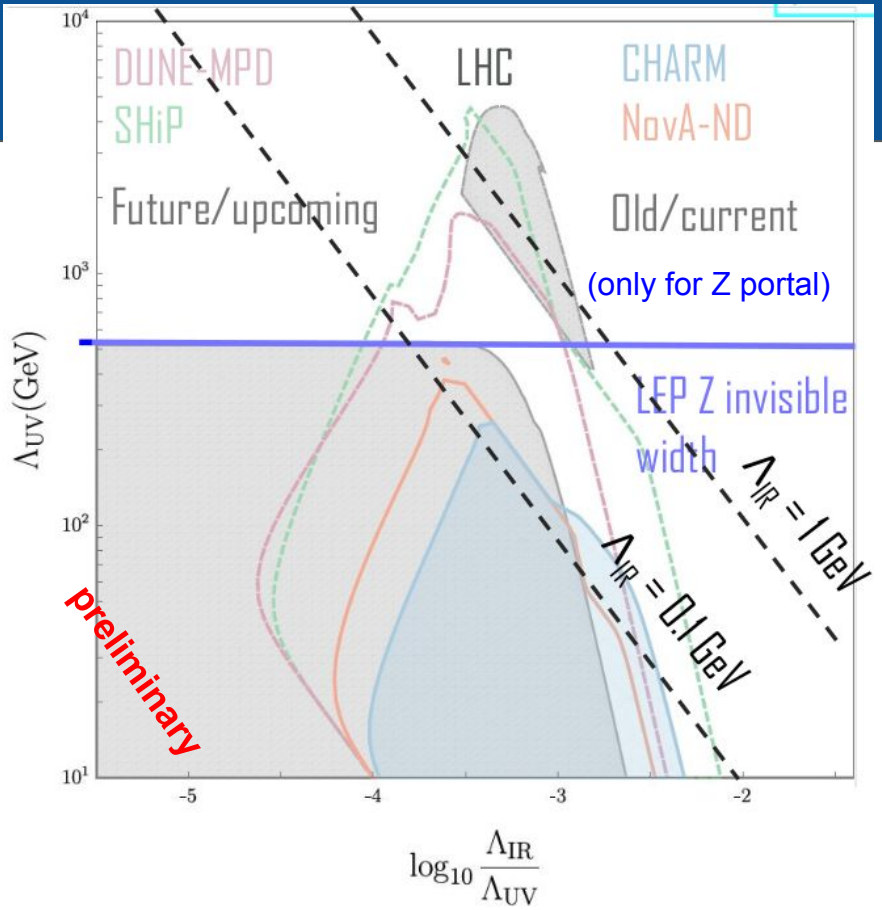

Conclusions

- Many possible light DM models
- Can we study them in a **model independent** way at high intensity/ν exp.?

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- **Production**: **Yes** for elusive DS models
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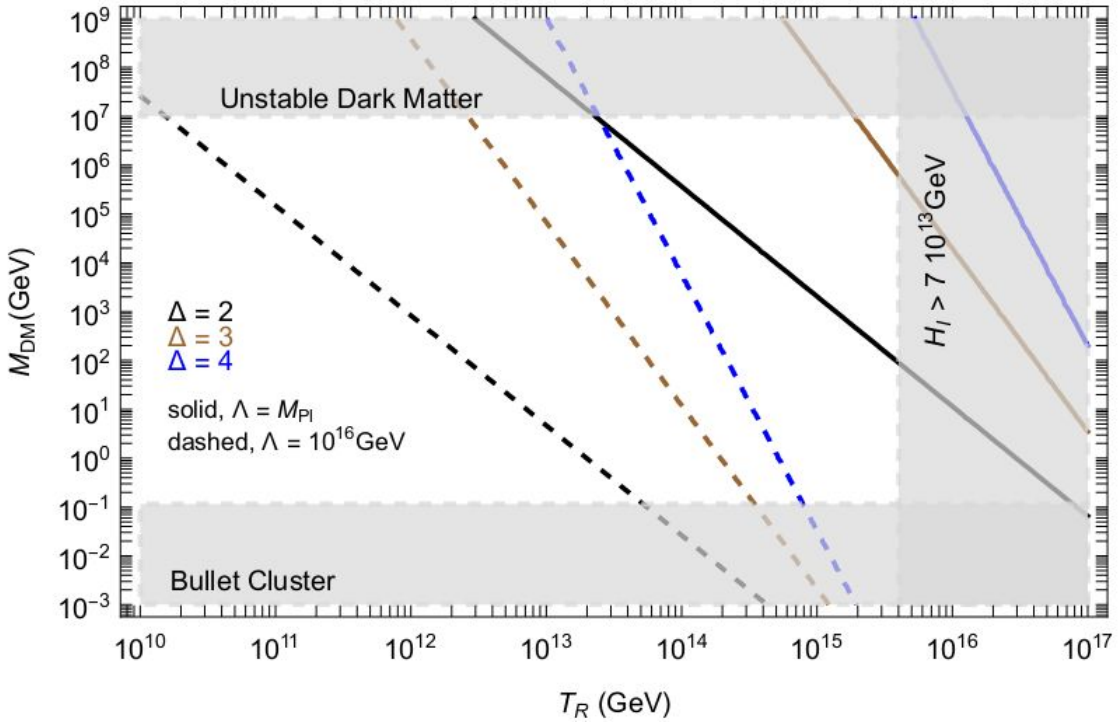
Conclusions

- Many possible light DM models
- Can we study them in a **model independent** way at high intensity/ν exp.?
- **Production**: **Yes** for elusive DS models
- **Decay signal**: depends only on spin and magnitude of single form factor
- Z portal/JJ portal can be probed at ν exp. (assuming bkg under control)
- Interesting region for masses in .1-1 GeV range.

Thanks for the attention!

Backup

Cosmology



Redi, Tesi 2107.14801

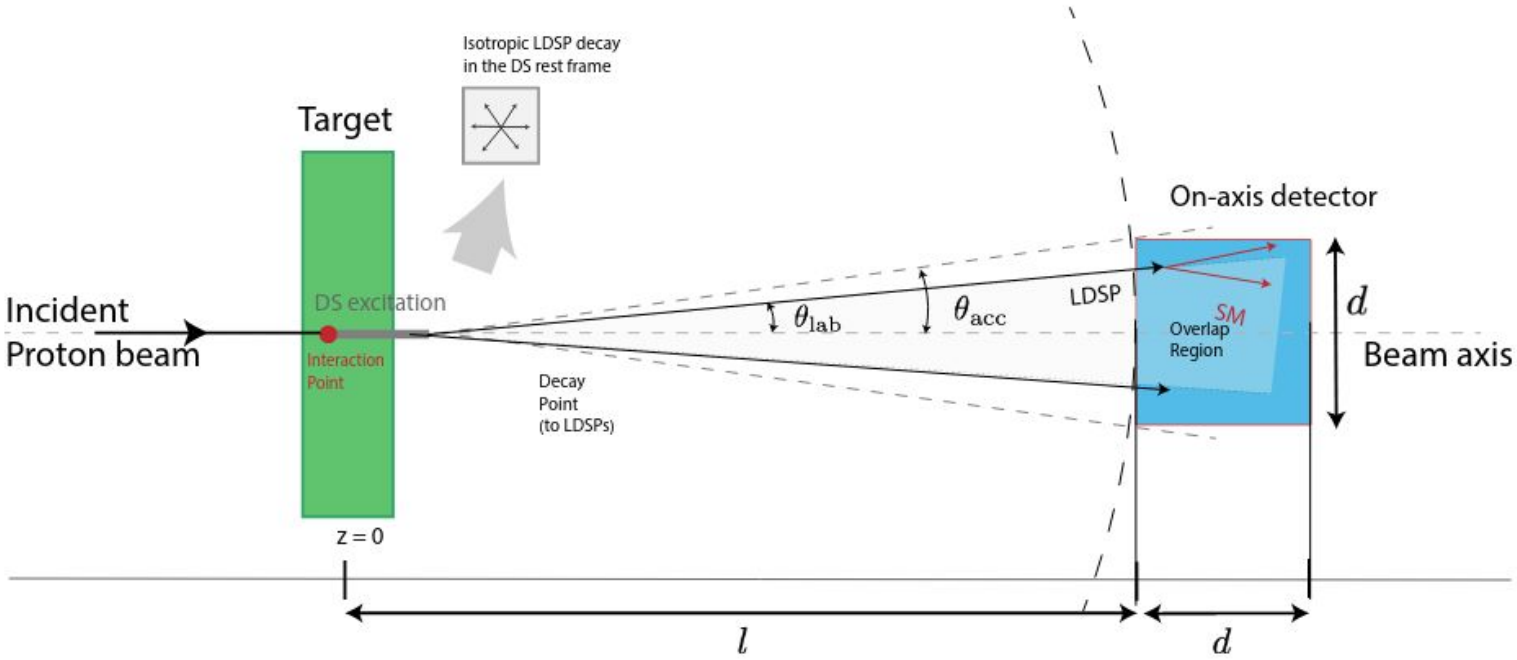
Hong, Kurup, Perelstein 1910.10160

From Redi, Tesi 2107.14801

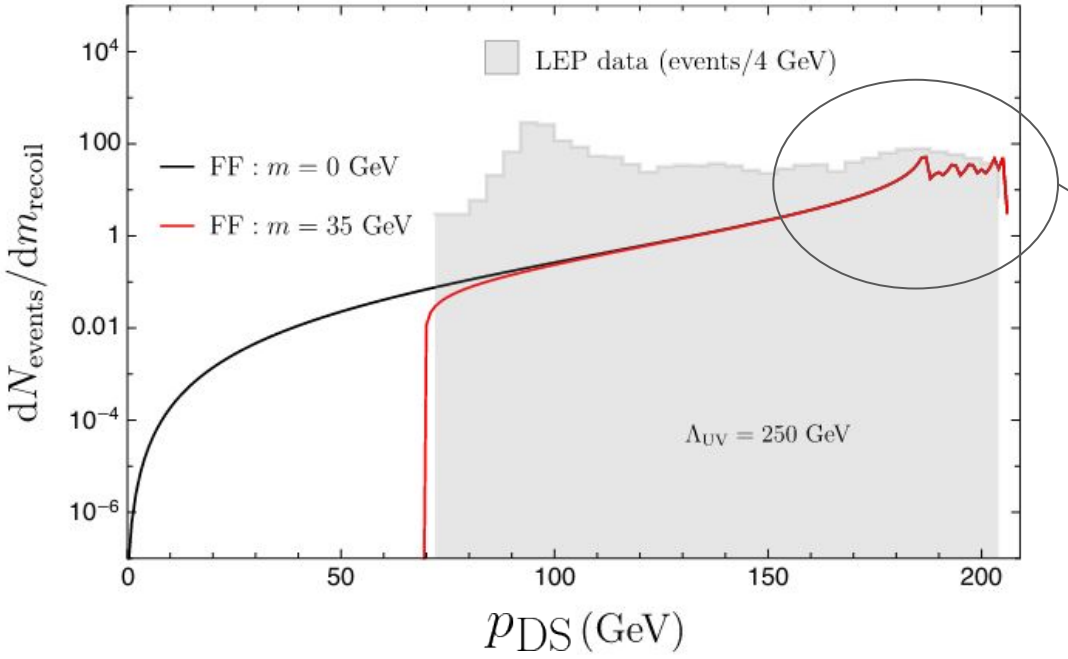
Freeze-in is a possibility
(although for very high cutoffs)

$$f_L H f_R \to CFT$$

Detection at ν experiments



Production through non-renormalizable portals



From Contino, Max, Mishra 2012.08537

Peak at high $p_{\rm DS}$

Strongly coupled benchmark

$$\langle n \rangle = A \left(\frac{1}{\log(\langle E \rangle^2 / \bar{\Lambda}^2)} \right)^B \exp\left(\frac{C}{\sqrt{\log(\langle E \rangle^2 / \bar{\Lambda}^2)}} \right), \qquad \begin{array}{ll} A = 0.06 & C = 1.8 \\ B = 0.5 & \bar{\Lambda} = 0.1\,\Lambda_{\rm IR} \end{array}$$

From Webber, Phys.Lett.B 143(1984) 501-504