Dark Ideas* from Strongly Coupled Theories

*Sectors

Based on works in collaboration with Marco Costa, Rashmish K. Mishra, Salvatore Bottaro, Roberto Contino

SCUOLA NORMALE SUPERIORE

Sonali Verma

DESY.

Convegno Nazionale Cortona 29 Sept 2023

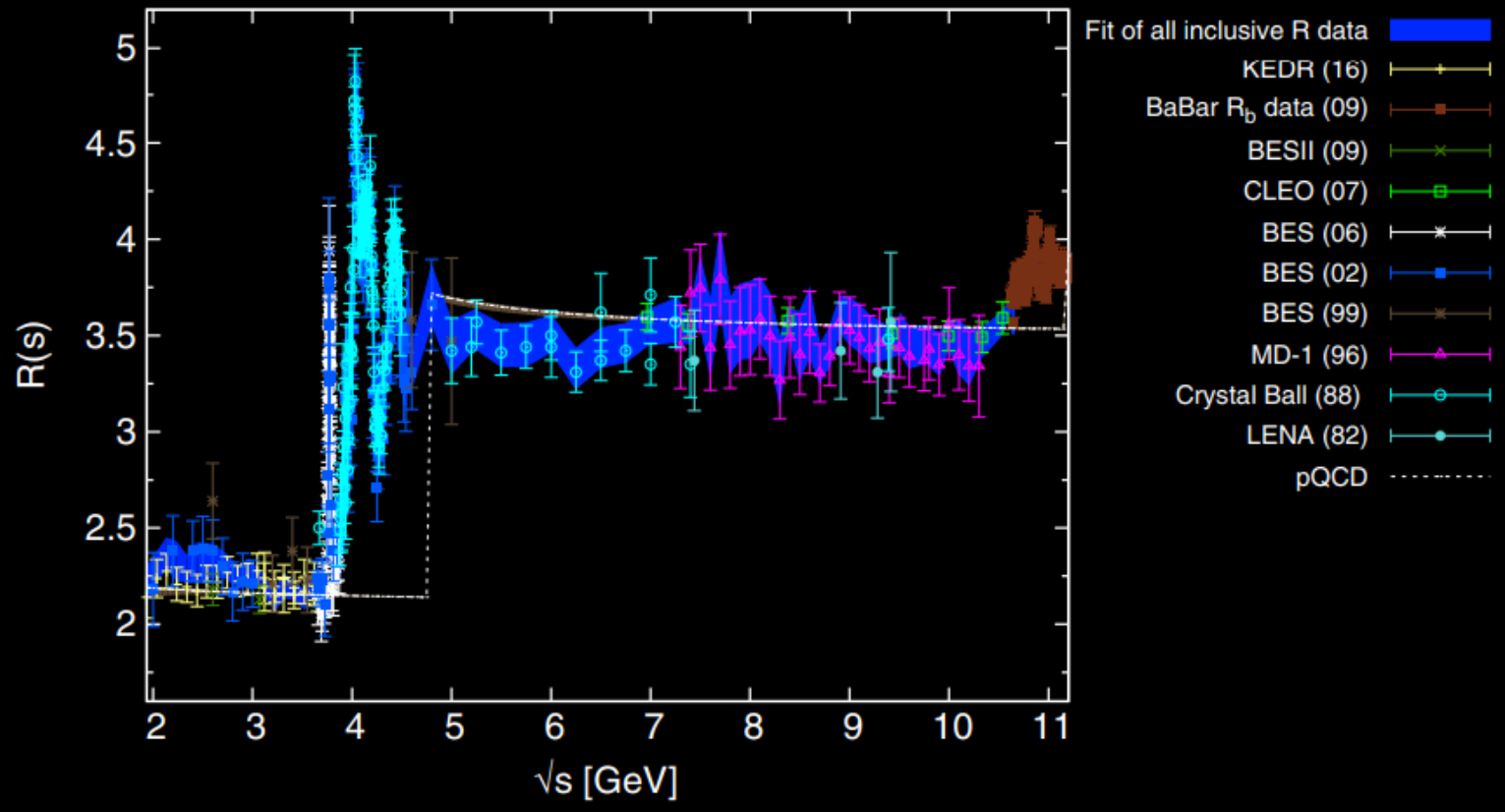
Lesson I from QCD

Based on Costa, Mishra, SV Phys. Rev. D 108 (2023) 3, 035041

Predictability away from thresholds

$$R(s) \equiv \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

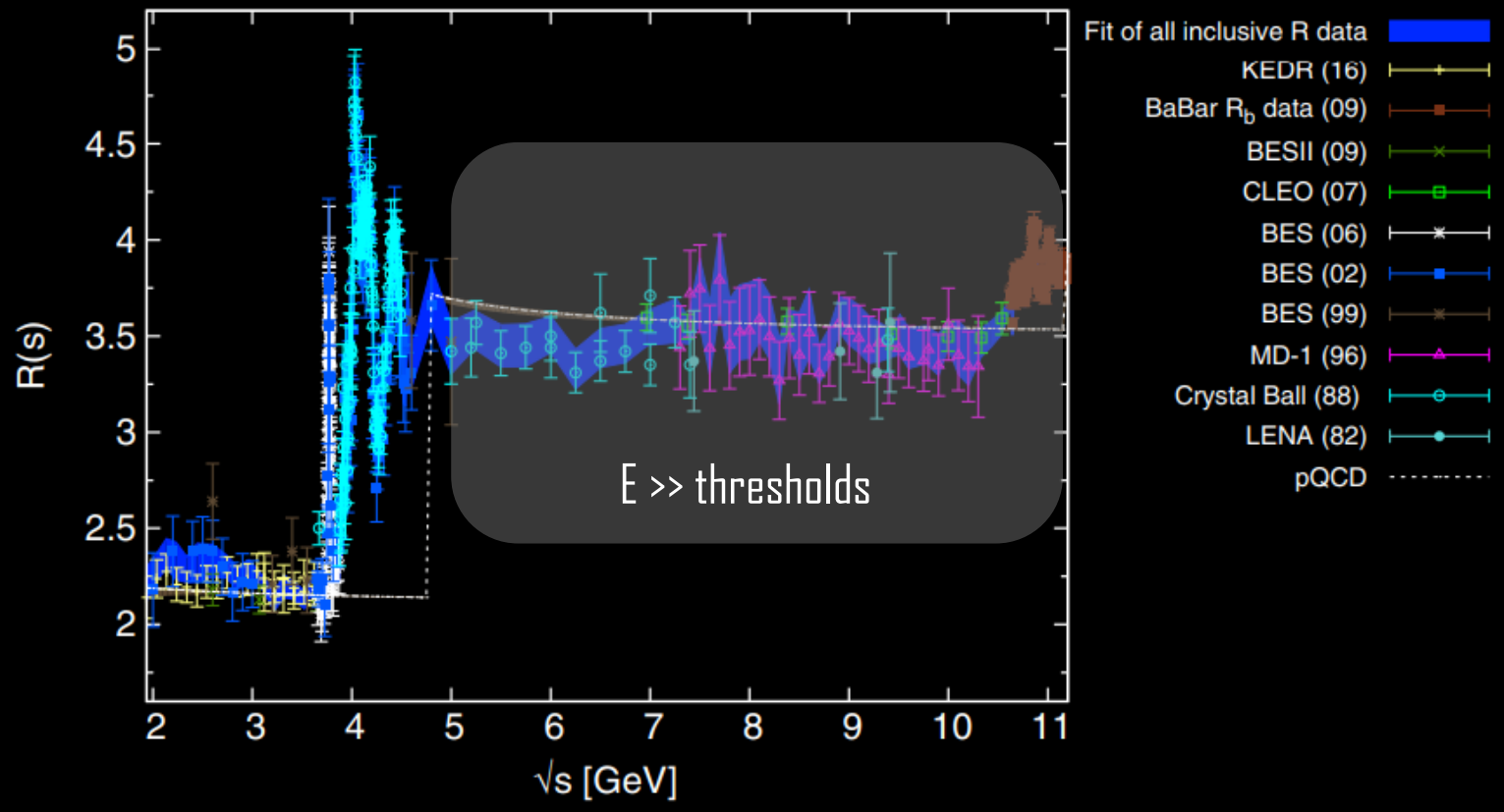
Keshavarzi, Nomura, Teubner, Phys. Rev. D 97 (2018) 114025



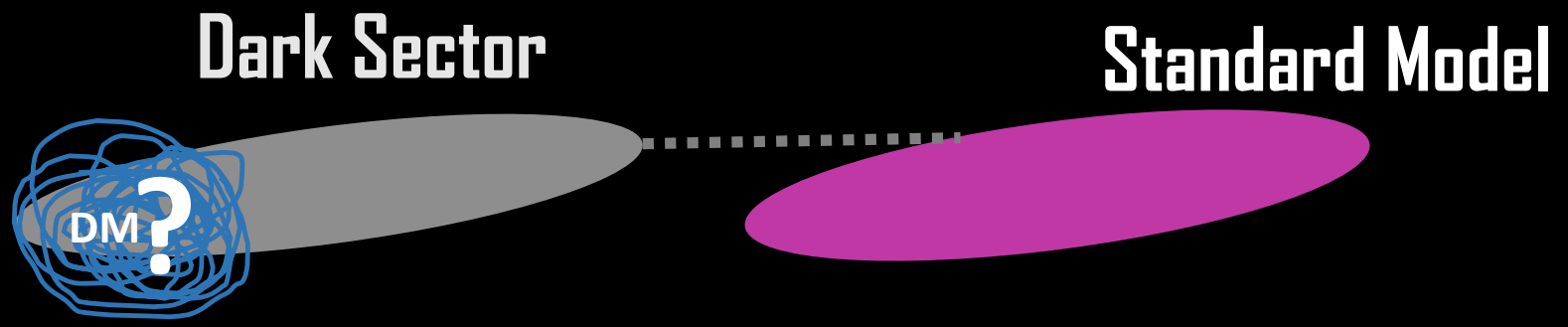
Predictability away from thresholds

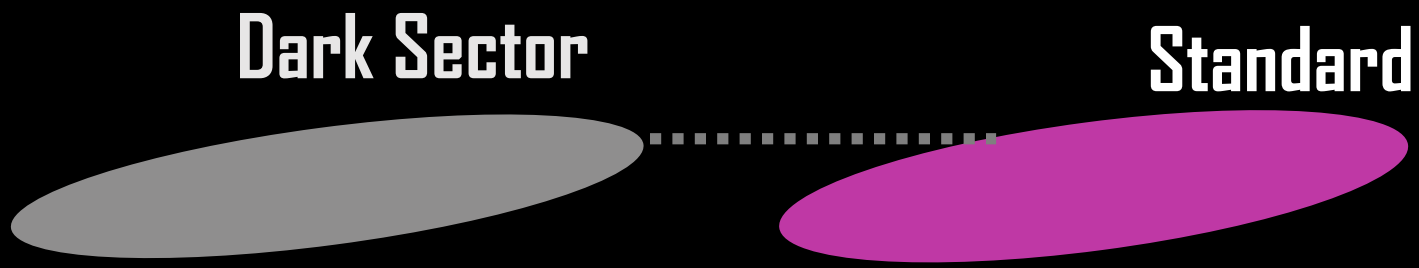
$$R(s) \equiv \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)} = 3\sum_f Q_f^2$$

Keshavarzi, Nomura, Teubner, Phys. Rev. D 97 (2018) 114025



See also Barbara Mele's talk

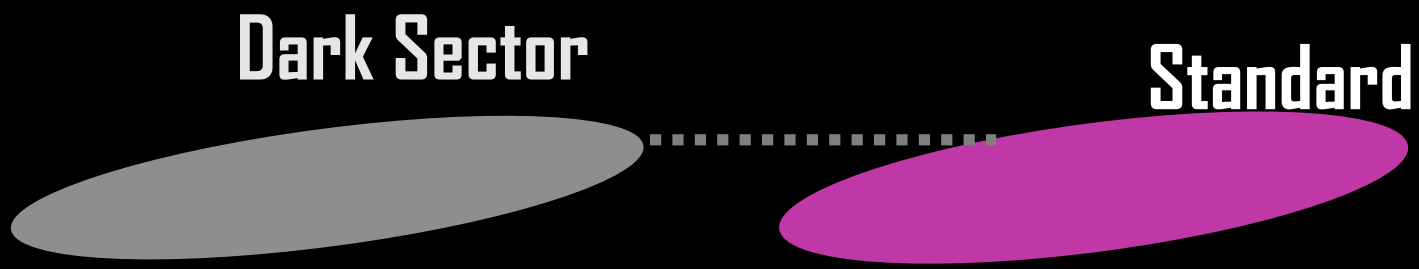




SM Singlet operator

$$\mathcal{L}_{\text{portal}} = \mathcal{O}_{DS}\mathcal{O}_{SM}$$

Dark sector
Singlet operator



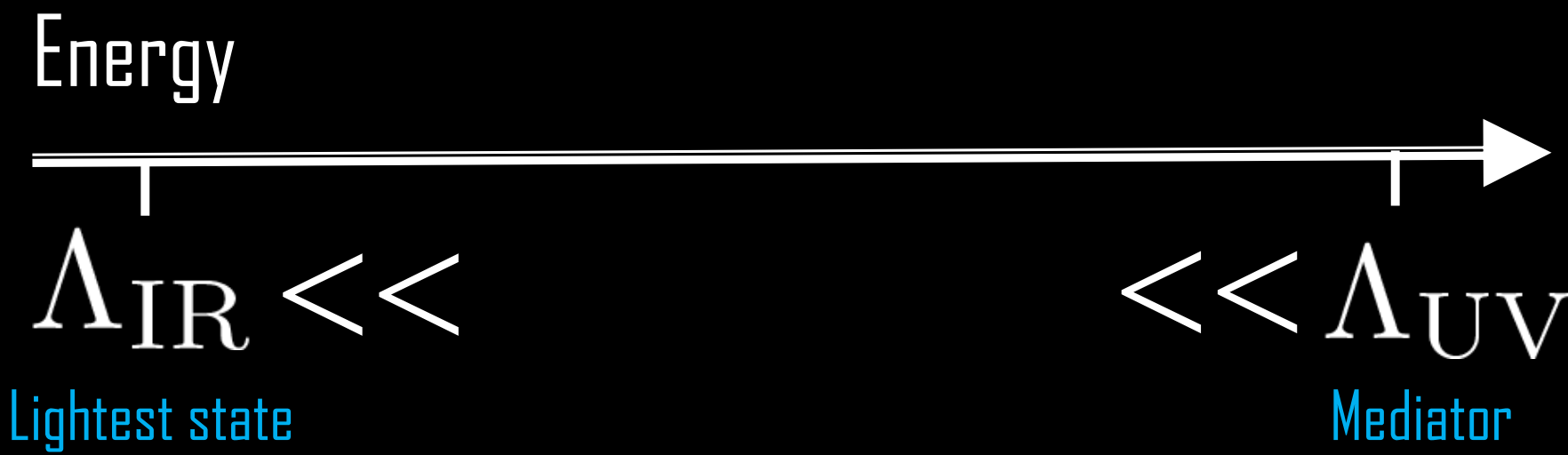
$$L_{\text{portal}} = \frac{\kappa}{\Lambda_{\text{UV}}^{D-4}} \mathcal{O}_{\text{DS}} \mathcal{O}_{\text{SM}}$$

$$\dim = [\mathcal{O}_{\text{SM}}] + [\mathcal{O}_{\text{DS}}] > 4$$

Irrelevant Portals

See also:
[Contino, Max, Mishra '20],
[Darme, Ellis, You '20],
[Cheng, Li, Salvioni '21]...

[Costa, Mishra, SV Phys. Rev. D 108 (2023) 3, 035041],
[Contino, Max, Mishra JHEP 06 (2021) 127]



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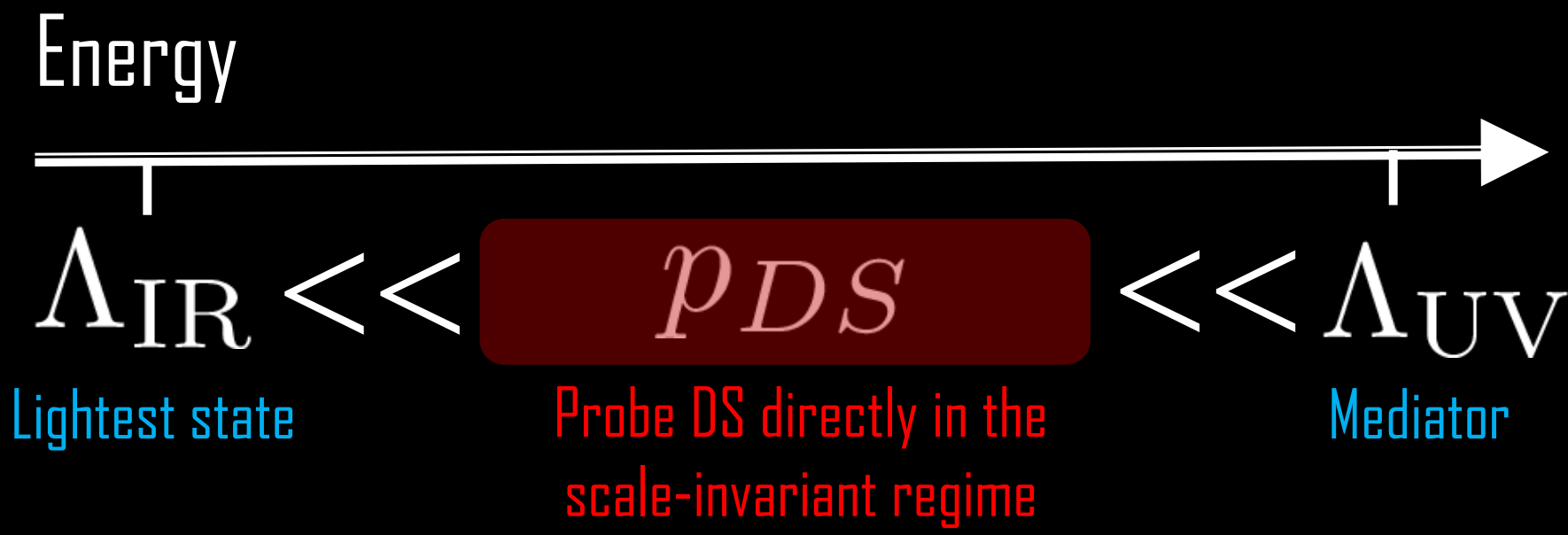
[Contino, Max, Mishra JHEP 06 (2021) 127]



Inclusive cross section for DS production

Optical Theorem

$$\sigma \propto \sum_n \int d\Phi_{\rm DS} |\langle 0|\mathcal{O}_{\rm DS}|n\rangle|^2 = 2\ {\rm Im}[i\langle 0|\mathcal{O}_{\rm DS}\mathcal{O}_{\rm DS}|0\rangle]$$

Inclusive cross section for DS production

E >> thresholds

From scale invariance

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Depends on dimension of DS operator

Approximate inclusive DS production cross section in a model agnostic way when well above threshold!

Inclusive cross section for DS production

E >> thresholds

From scale invariance

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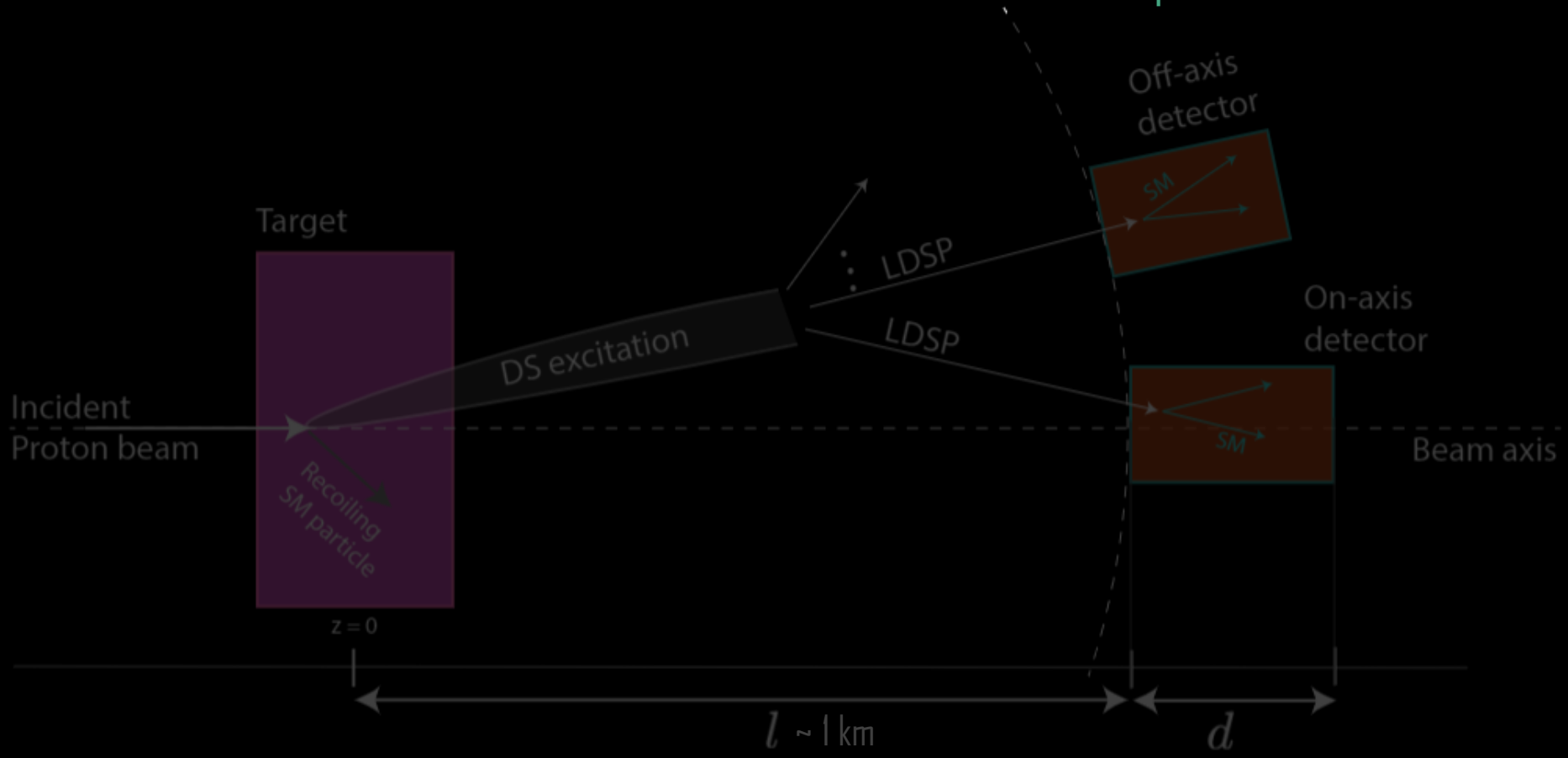
Depends on dimension of DS operator

At neutrino experiments?

For bounds at other experiments, see Contino, Max, Mishra '20



Costa, Mishra, SV Phys. Rev. D 108 (2023) 3, 035041

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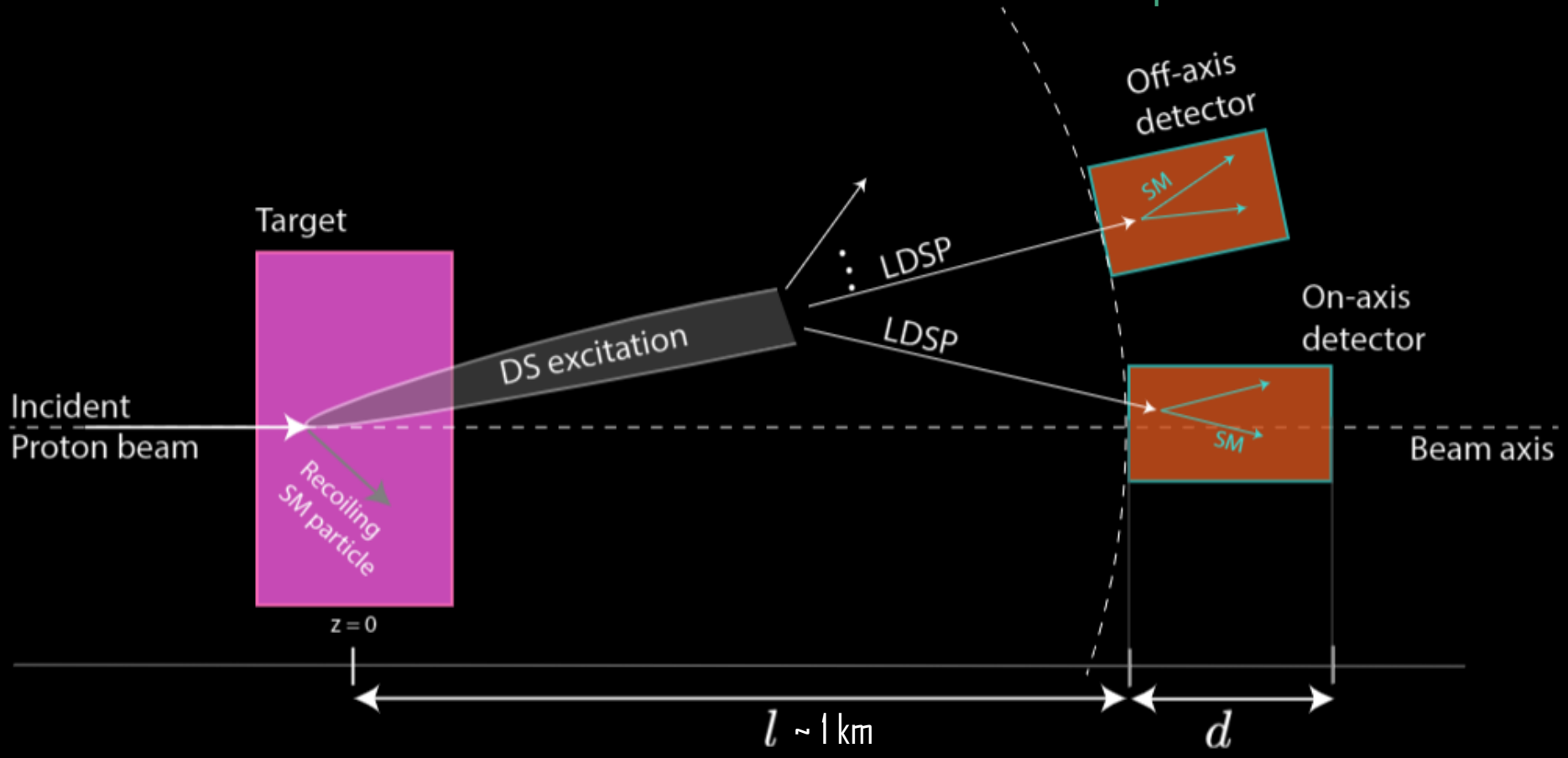


Costa, Mishra, SV Phys. Rev. D 108 (2023) 3, 035041

Constraints?

Costa, Mishra, SV Phys. Rev. D 108 (2023) 3, 035041

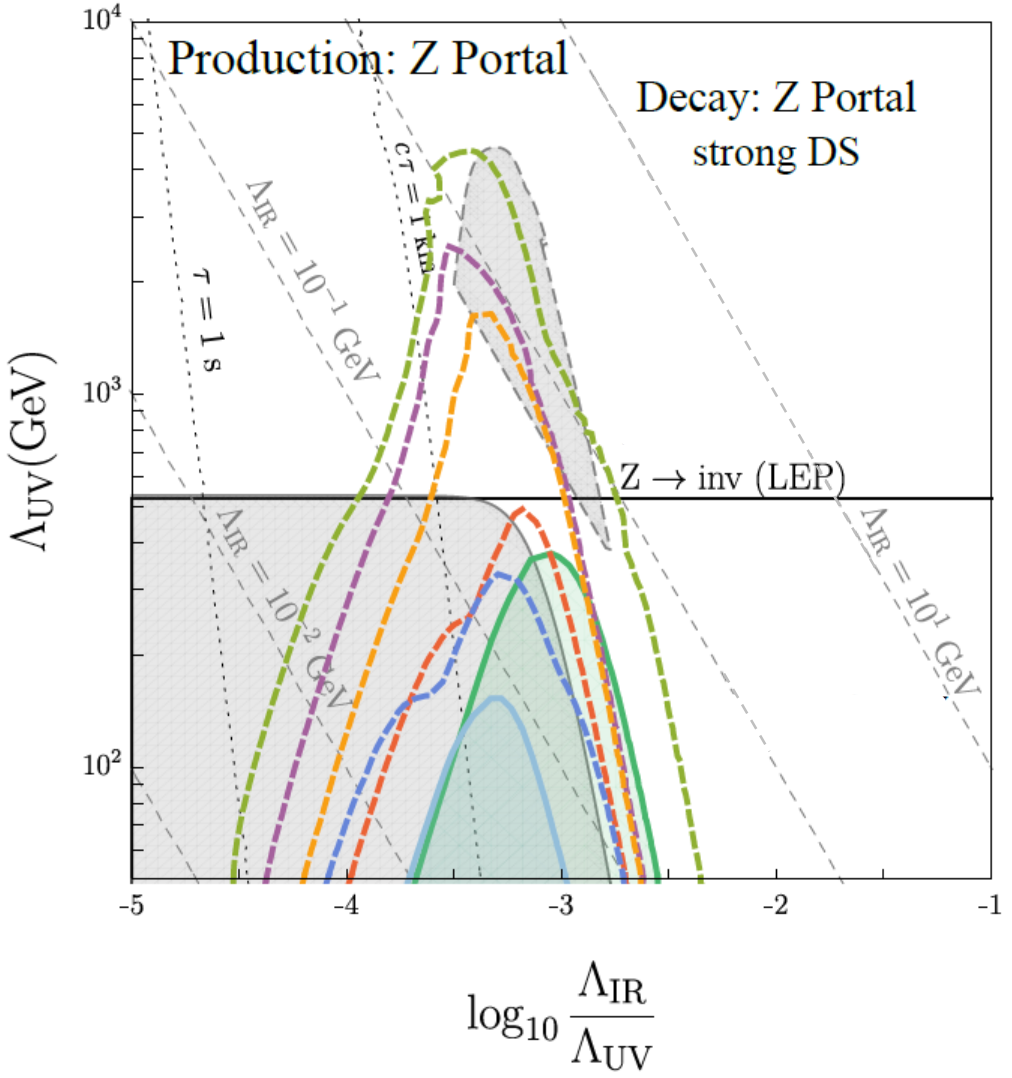
LHC

CHARM
MicroBoone-KDAR

ICARUS-NUMI
NovA-ND

DUNE-MPD [10]
DUNE-MPD [100]

SHiP



Portal: $H^\dagger i D_\mu H J^\mu_{DS}$

$v m_z Z_\mu J^\mu_{DS}$

Lesson II from QCD

Based on Bottaro, Contino, SV [To Appear]

Creation of hierarchies

RG equation

$$\frac{d\,\alpha(\mu)}{d\,ln\,\mu} = \beta(\alpha)$$

2 flavours, at 1-loop

$$\beta(\alpha_{QCD}) = -\frac{29}{6\pi}\alpha^2_{QCD}(\mu)$$

$$m_p = M_{Pl}\, e^{-1/C\;\alpha_{QCD}(M_{Pl})}$$

$$m_p/M_{Pl} \sim 10^{-18}$$

$$\alpha_{QCD}(M_{Pl}) \sim 10^{-2}$$

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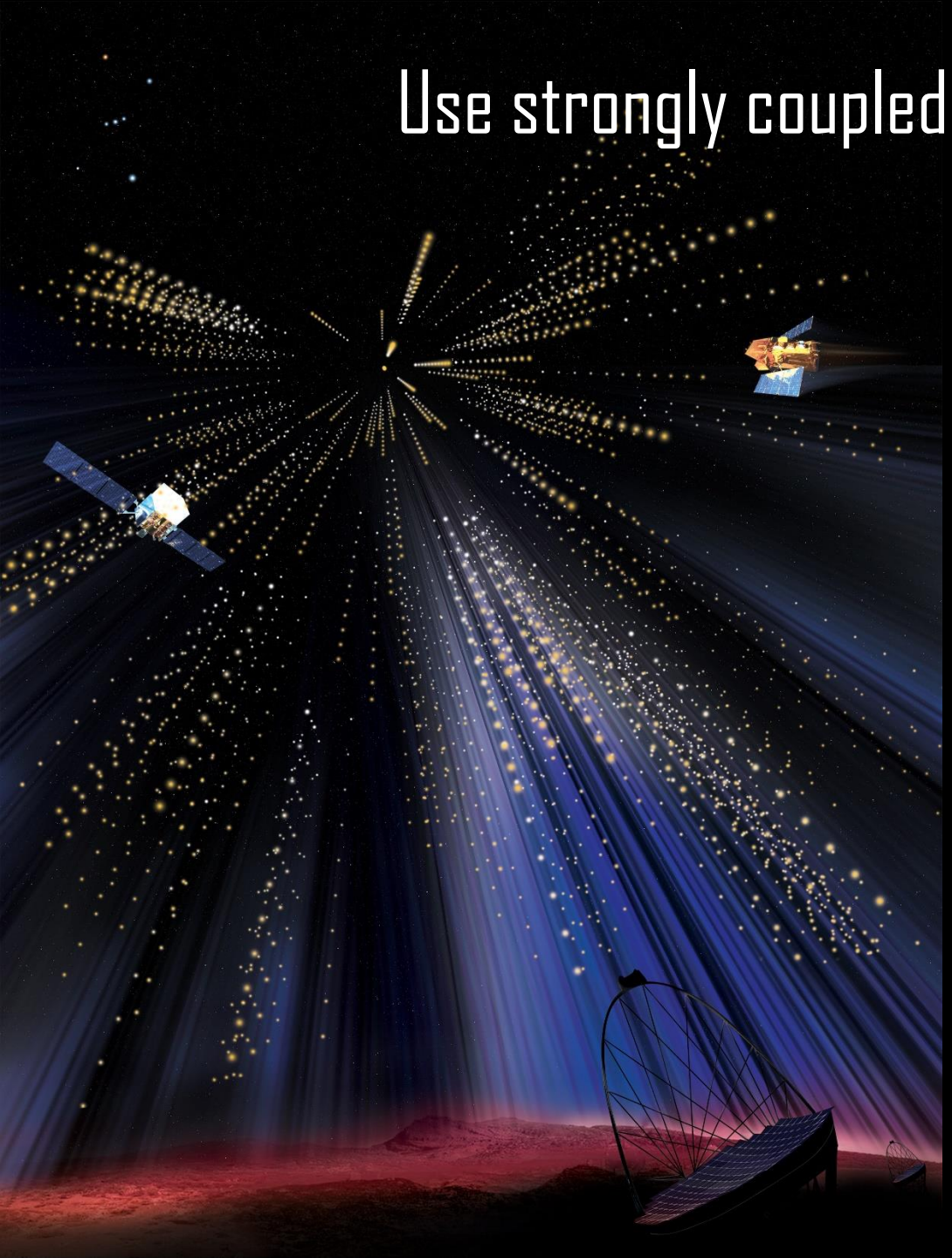
Use strongly coupled theory for Dark Matter (DM) stability



From indirect detection bounds

$$\tau_{DM} \geq 10^{28}\ \text{sec}$$

$$\Gamma \sim \frac{\kappa}{8\pi} \frac{m_{DM}^{2D-7}}{\Lambda_{UV}^{2D-8}}$$

$$D = 6, \quad m_{DM} \sim 10 - 100\ \text{TeV} \Rightarrow \frac{m_{DM}}{\Lambda_{UV}} \sim 10^{-14} - 10^{-15}$$

$$SU(N)_{DC} \times \mathcal{G}_{SM}$$

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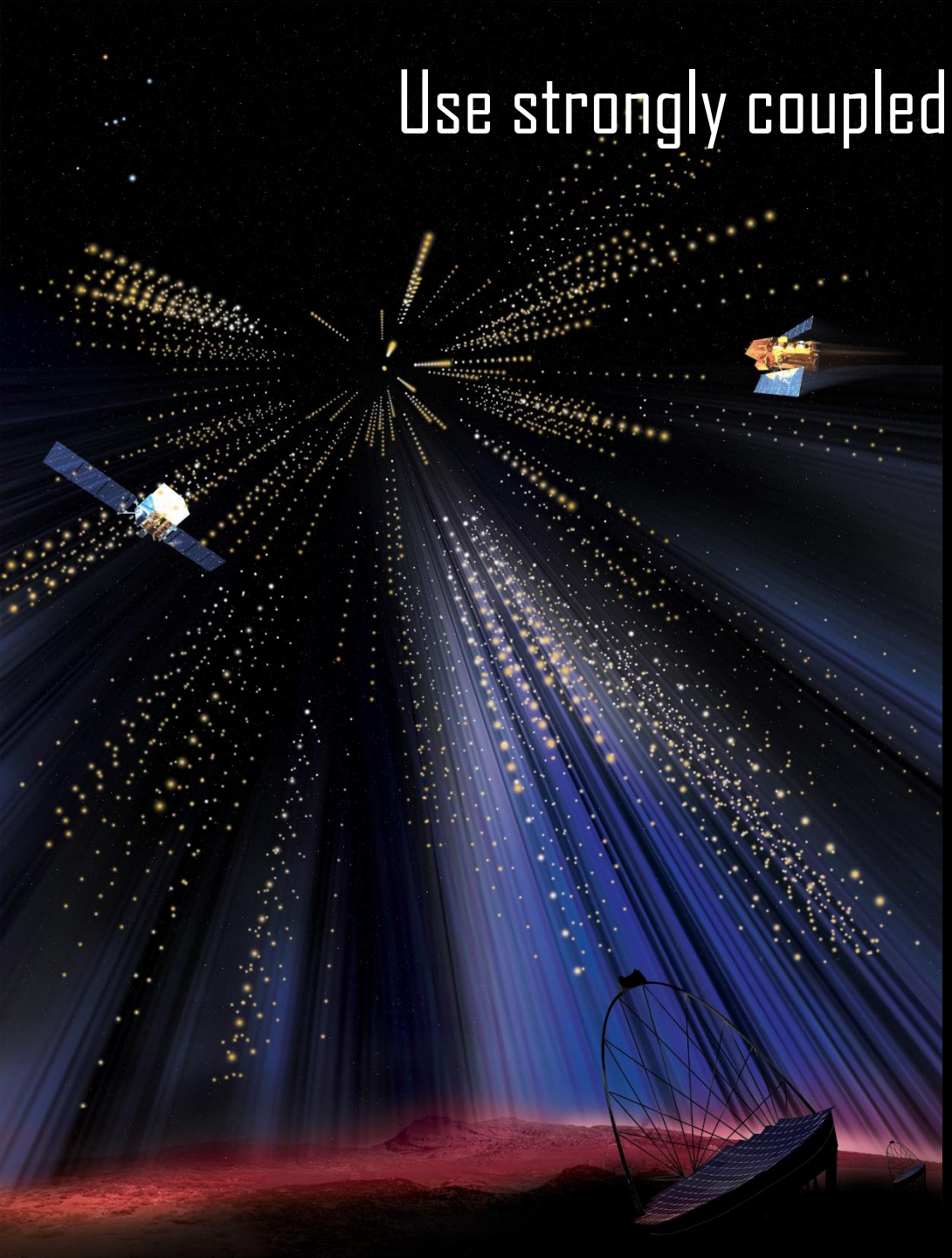

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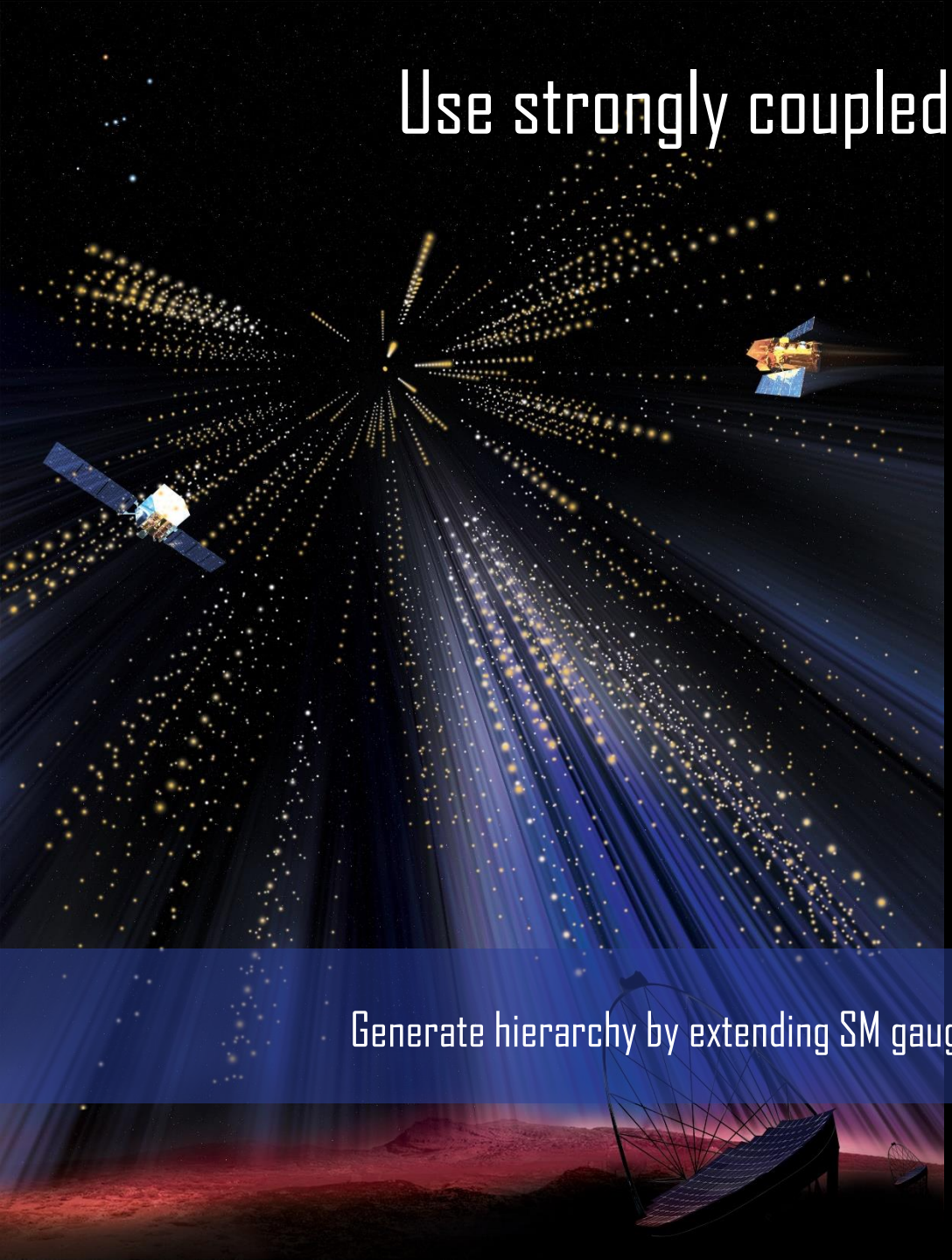

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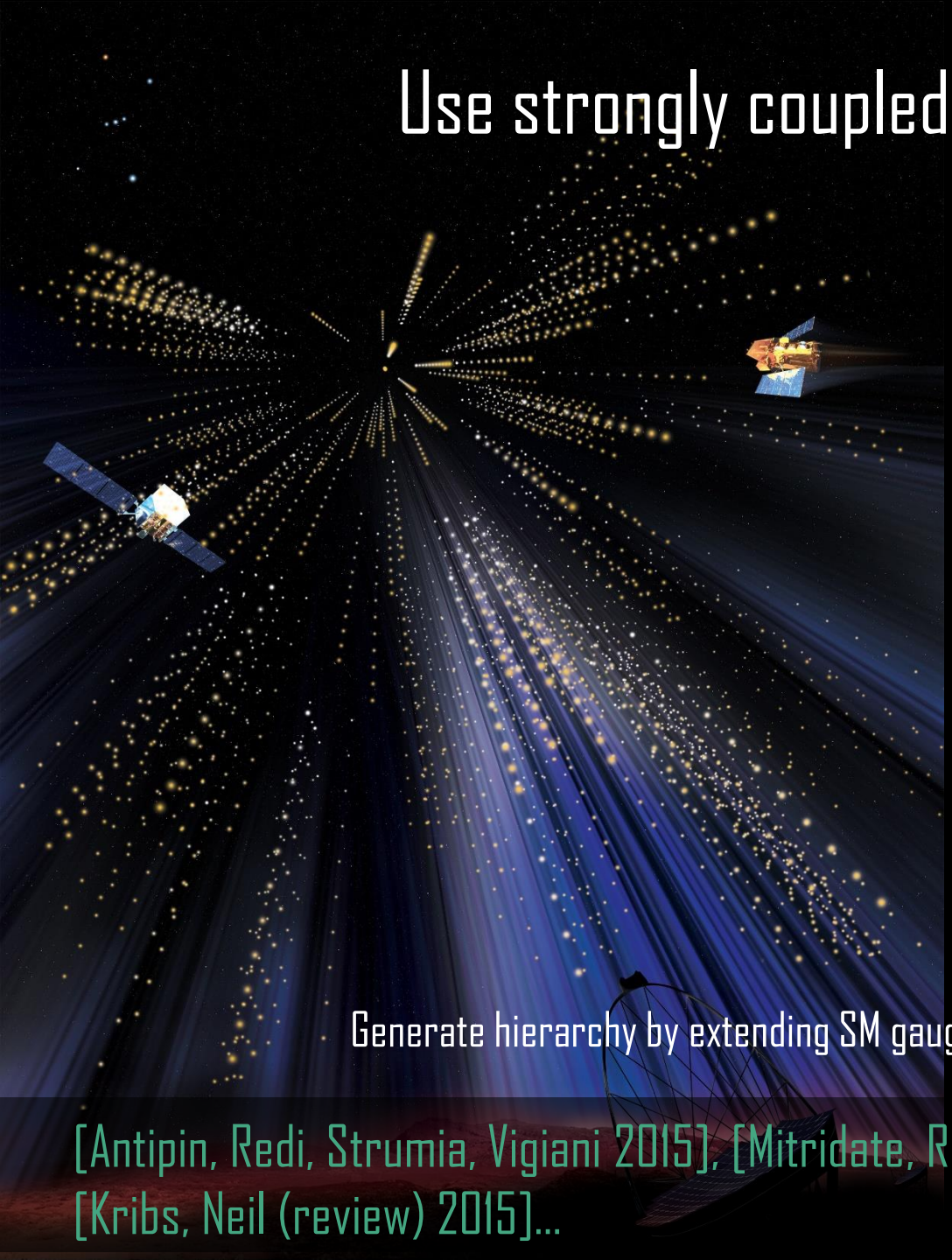

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[Antipin, Redi, Strumia, Vigiani 2015], [Mitridate, Redi, Smirnov, Strumia 2017], [Contino, Mitridate, Podo, Redi 2019], [Kribs, Neil (review) 2015]...

Dark Sector

Vector-like dark theory

Lightest Dark baryon $\Omega_{DM} \sim 0.1 \quad M_{DM} \sim 100\ \mathrm{TeV}$

Dark colour confines

Mass of dark fermions

IR theory $m_L \lesssim \Lambda_{DC}$

$SU(N)_{DC} \times \mathcal{G}_{SM}$

Antipin, Redi, Strumia, Vigiani '15

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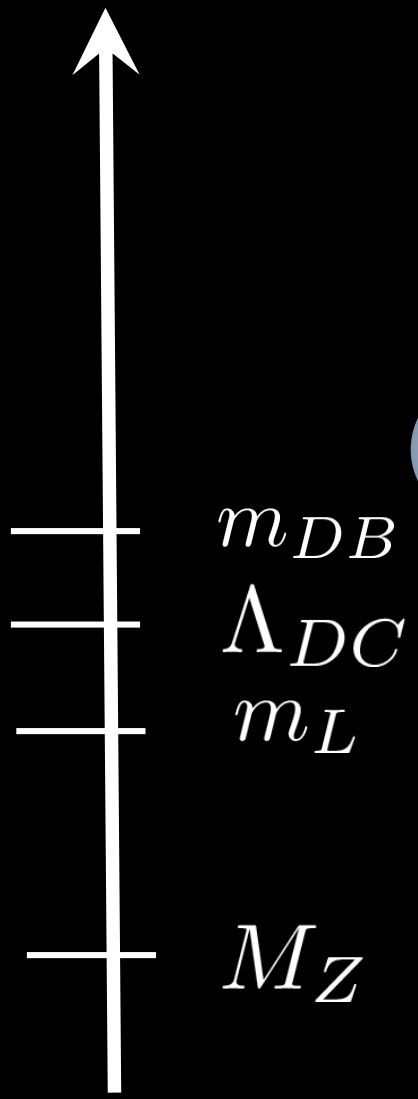

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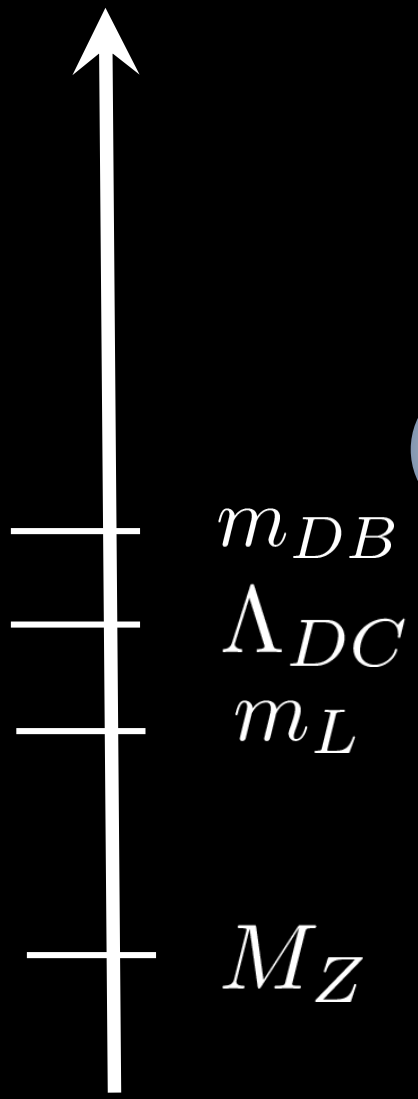

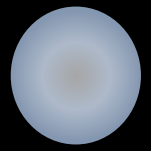

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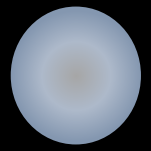
Bottaro, Contino, SV [To Appear]

M_{GUT} GUT breaks

UV theory $SU(N)_{DC} \times SU(5)_{GUT}$



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M_Z

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Bottaro, Contino, SV [To Appear]

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Study impact of GUT partners

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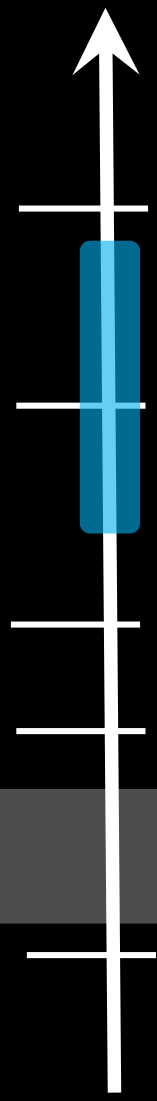

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Can we build a realistic theory consistent with composite DM and unification?

M_Z

Constraints?

Contino, Bottaro, SV [To appear]

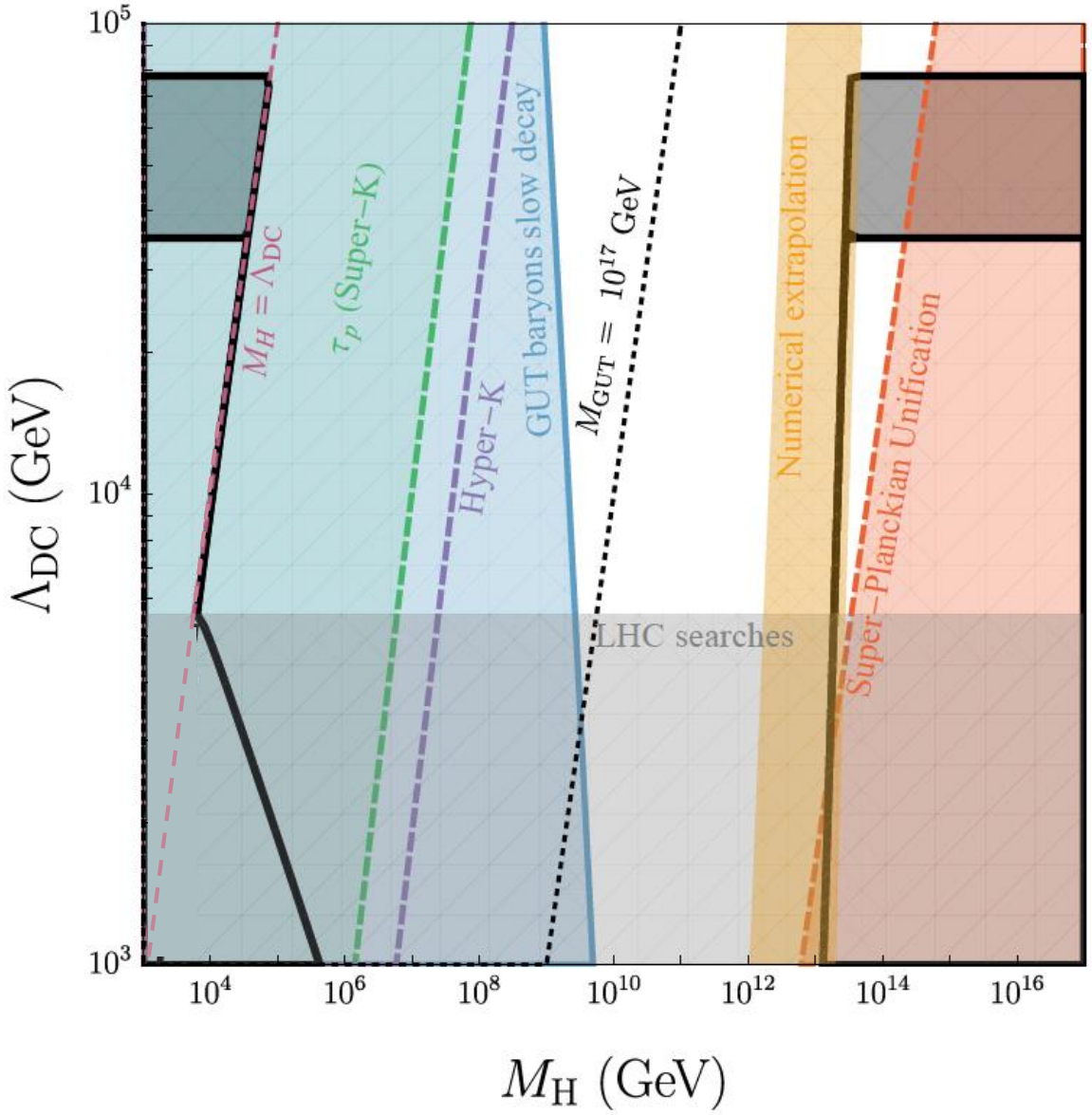
$\Omega_{DM}h^2 = 0.12$

Non-perturbative uncertainties

Proton lifetime

Late unification

Big Bang Nucleosynthesis



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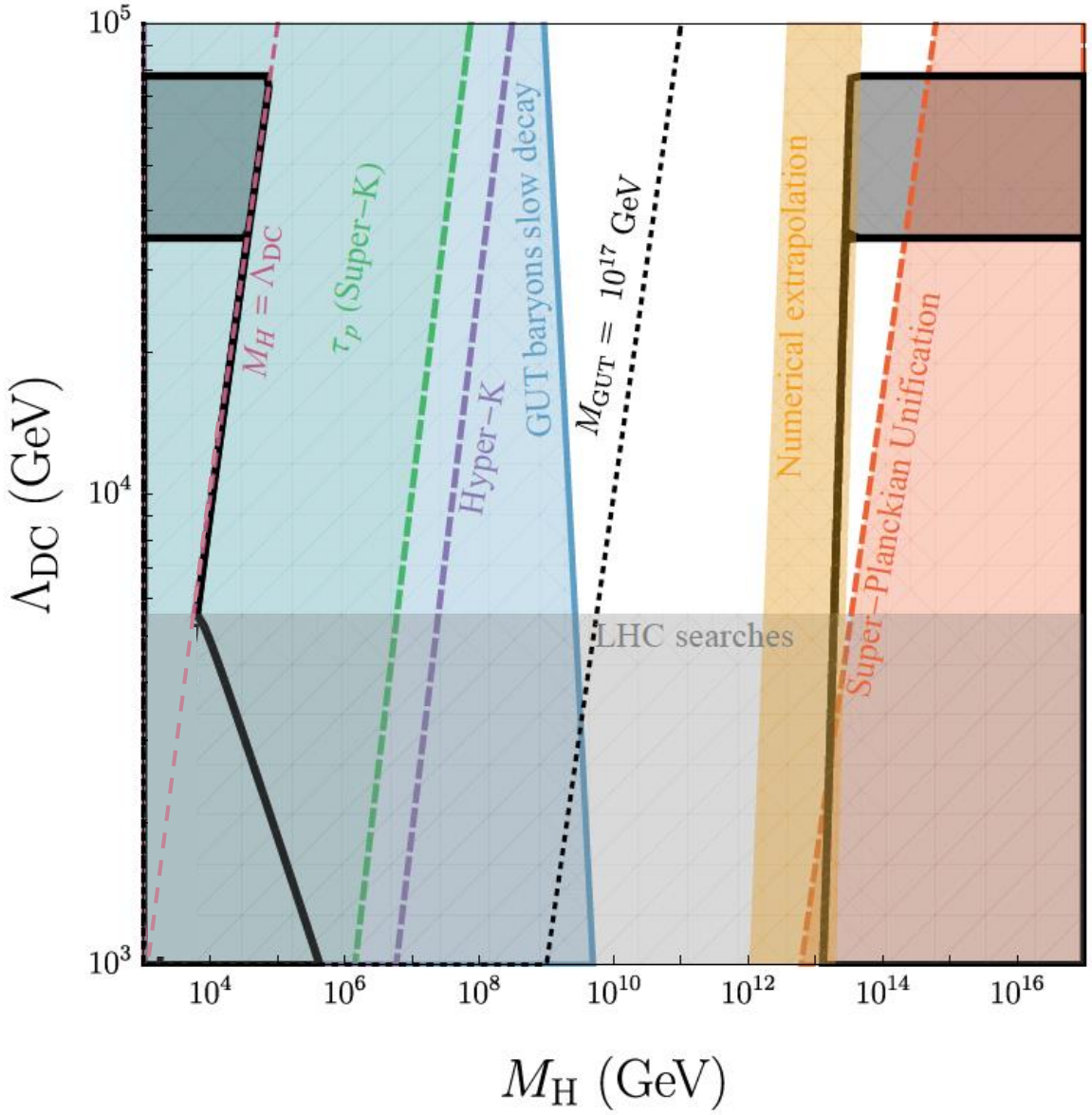

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Conclusions

- Strongly coupled theories give elegant ideas for dark sectors
- Probe dark sectors in the scale invariant regime to be model agnostic
- Future neutrino oscillation experiments will be powerful probes
- Use SU(5) GUT UV completion as an additional theory prior – very constraining
- Way ahead: Can we use non-gaussianities to probe the SU(5) dark GUT model?

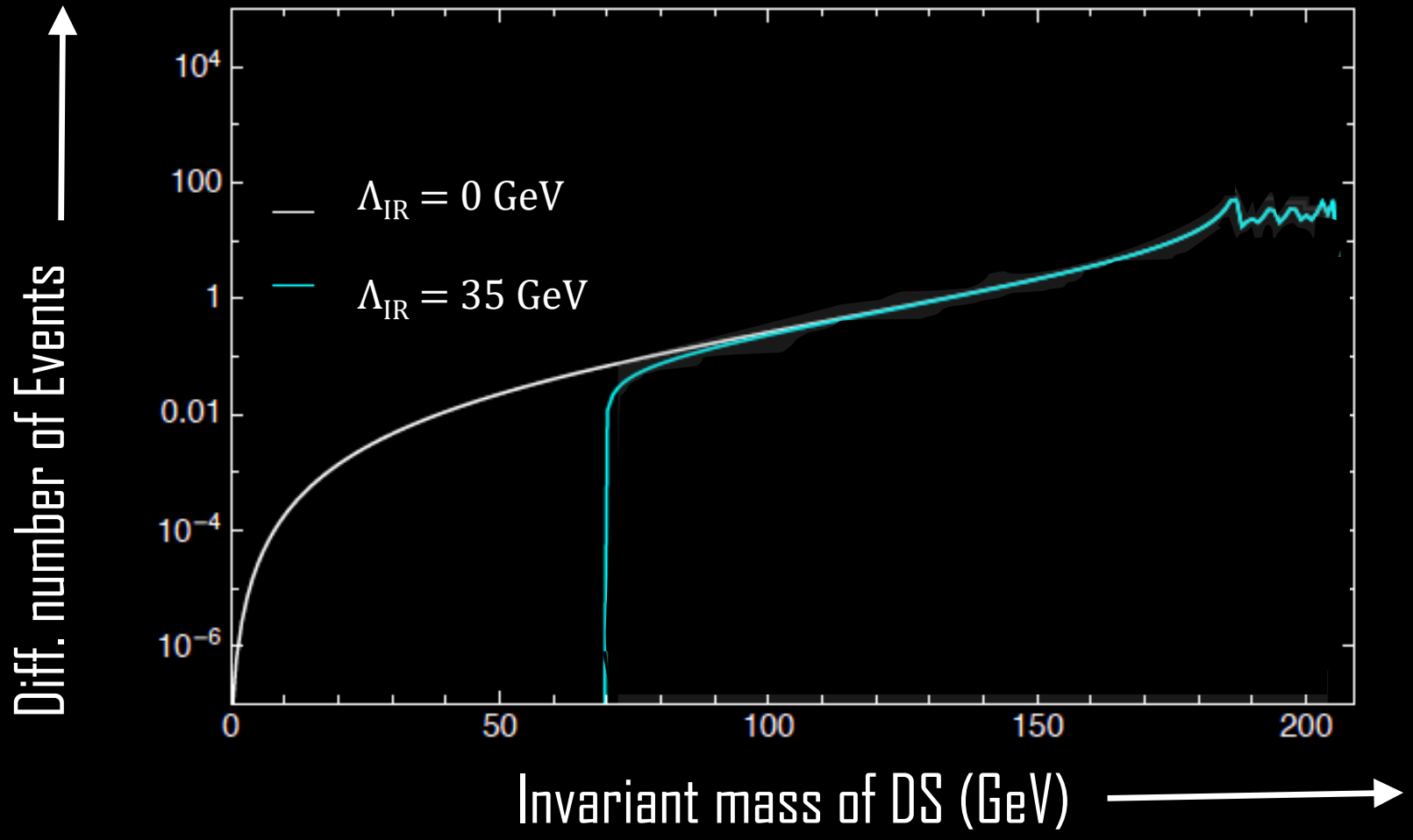

Camucia Stazione
15A
20S
22S
LS6
SFS
ST5
SU4
SU5
REGIONE TOSCANA
22S 22S-RIGUTIN FR. PLANET
SU4 SU4-CORTON MERCATO
ST5 ST5-CAPEZZIN (ISTITUTO AG
15A 15A-FOIANO BAR

Back-up

How good is the approximation?

Contino, Max, Mishra 2012.08537

Free Fermion DS: 1 Majorana fermion + 1 scalar (integrated out)



$$\frac{1}{m_\phi^2}\bar{e}_R\gamma_\mu e_R\bar{\chi}\gamma^\mu\gamma^5\chi$$

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Contino, Max, Mishra 2012.08537

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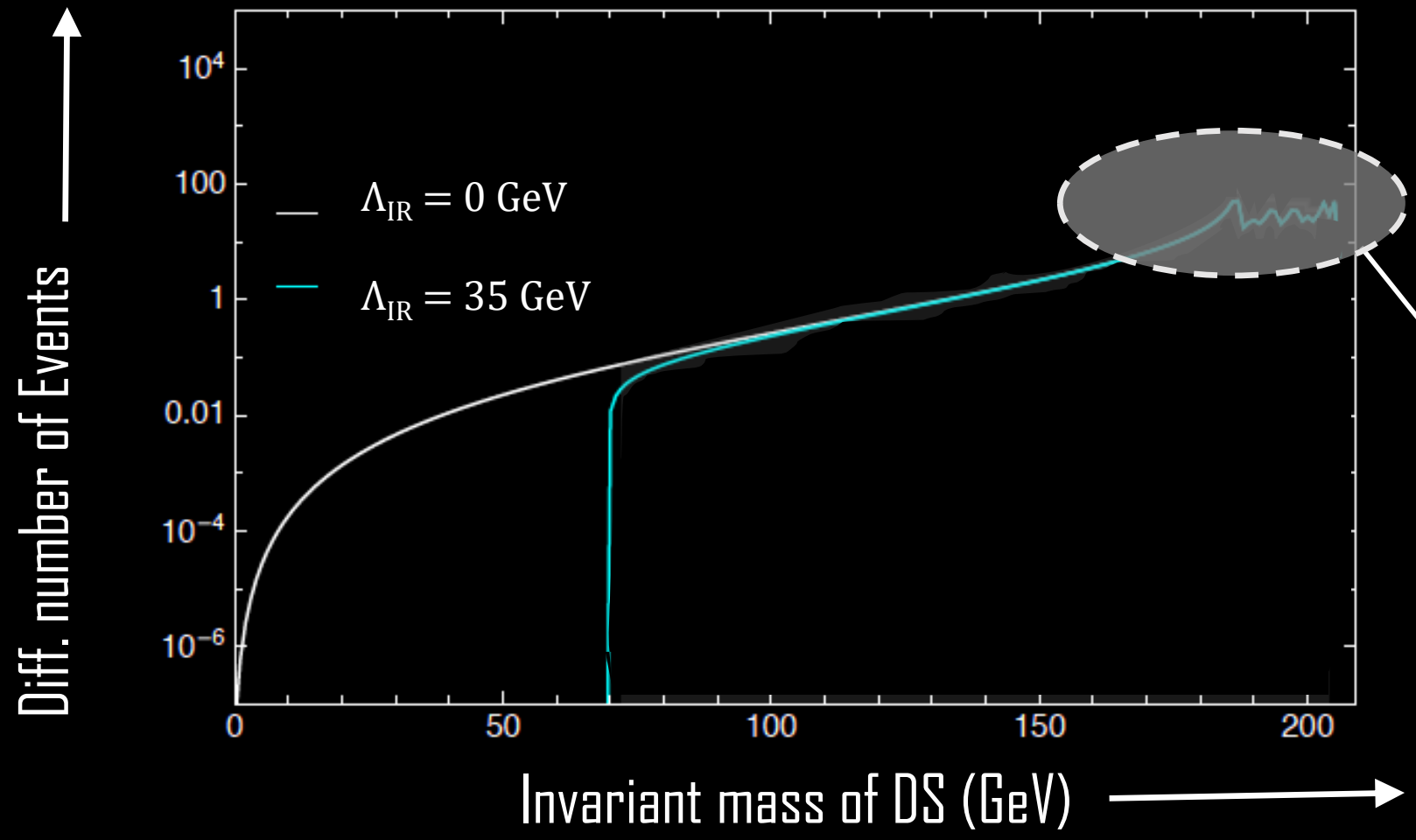


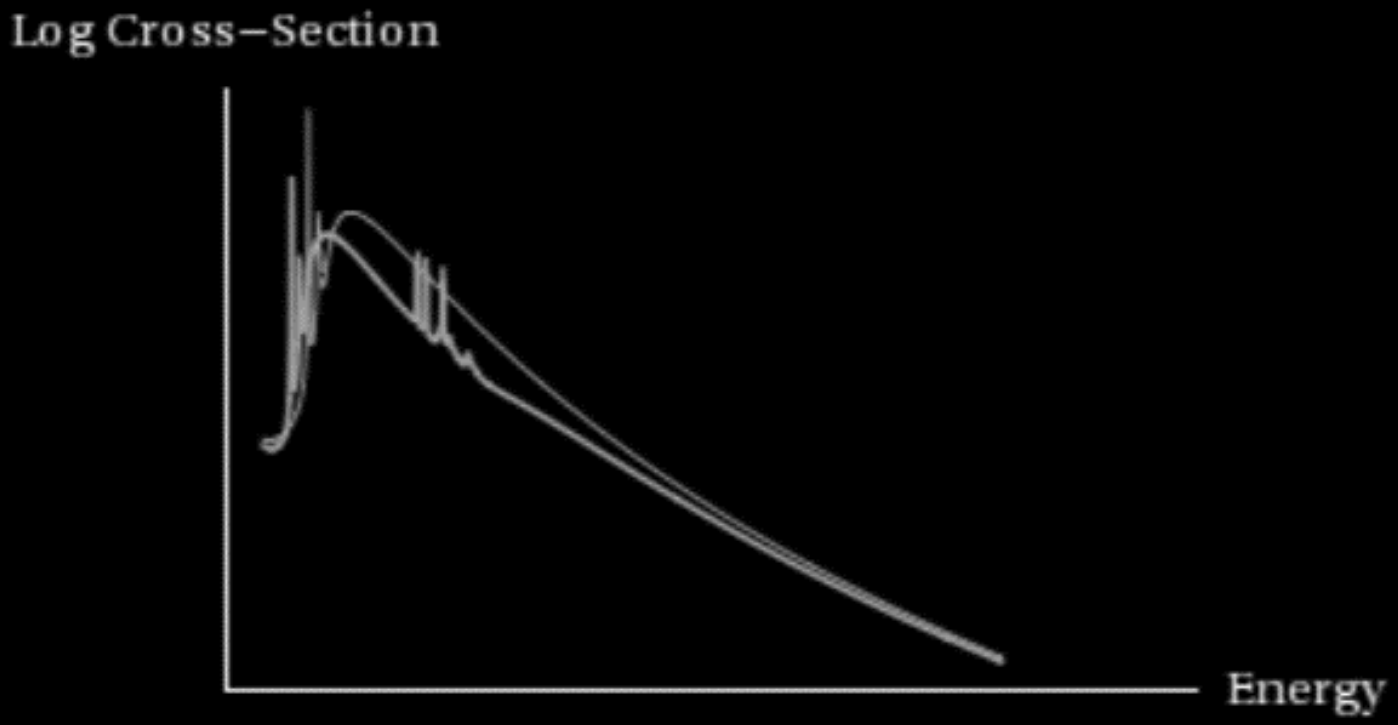
$$\frac{1}{m_\phi^2}\bar{e}_R\gamma_\mu e_R\bar{\chi}\gamma^\mu\gamma^5\chi$$

Largest contribution at high p_{DS}^2 away from threshold

Be careful about EFT validity!

For relevant portals: See Strassler arXiv:0801.0629

$$\mathcal{O}_{\rm DS} H^\dagger H \qquad \Delta_{\mathcal{O}} < 2$$



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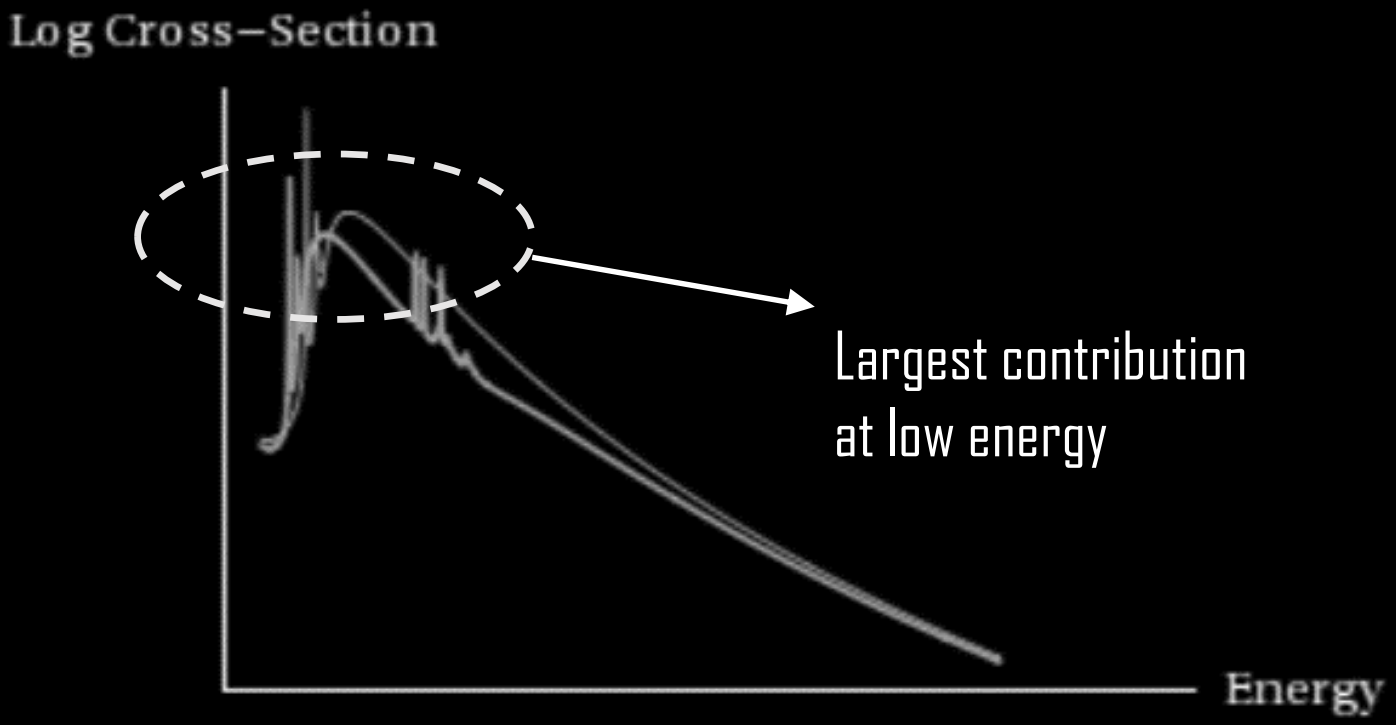
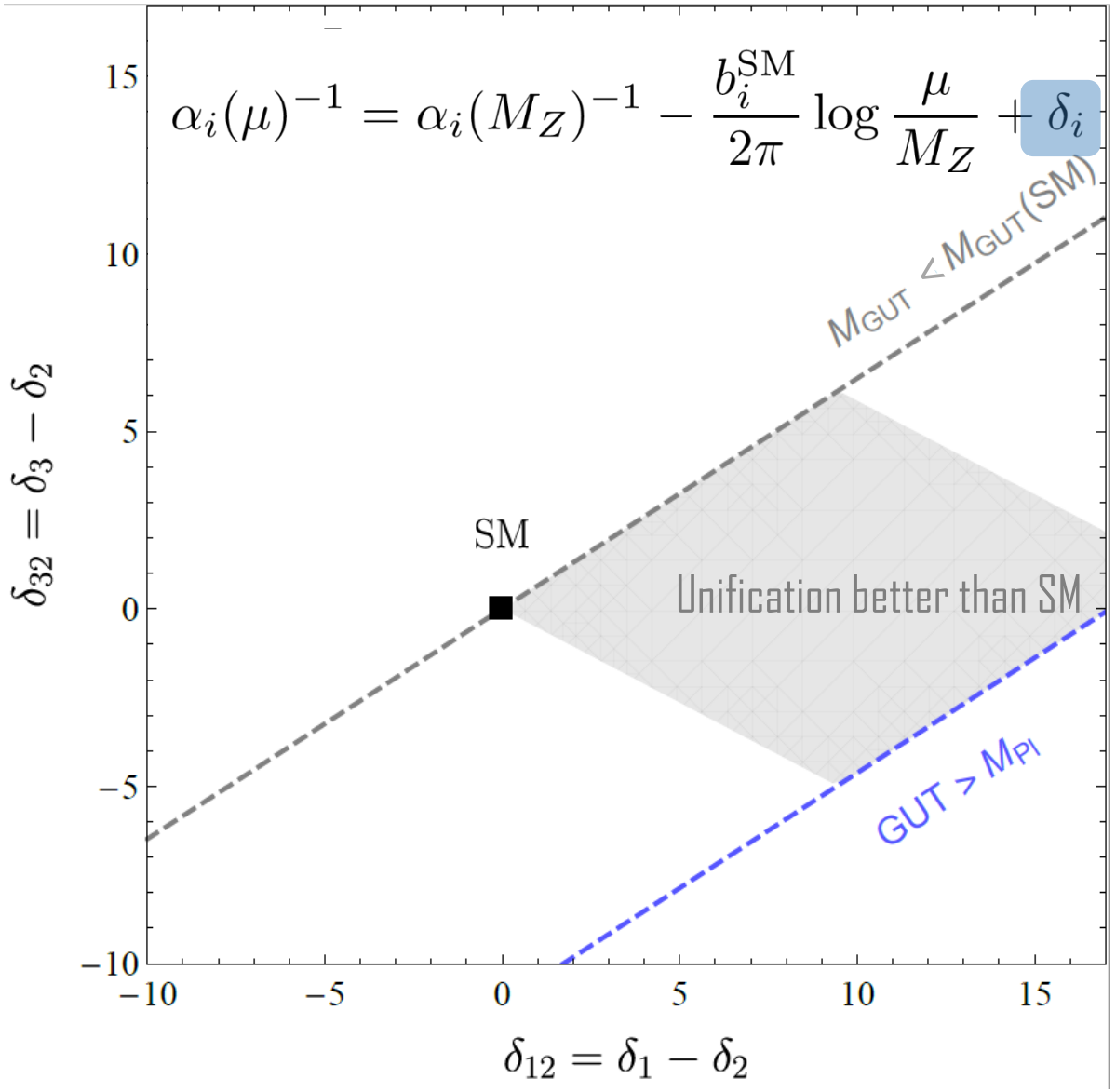


Good models?

Bottaro, Contino, SV [To Appear]

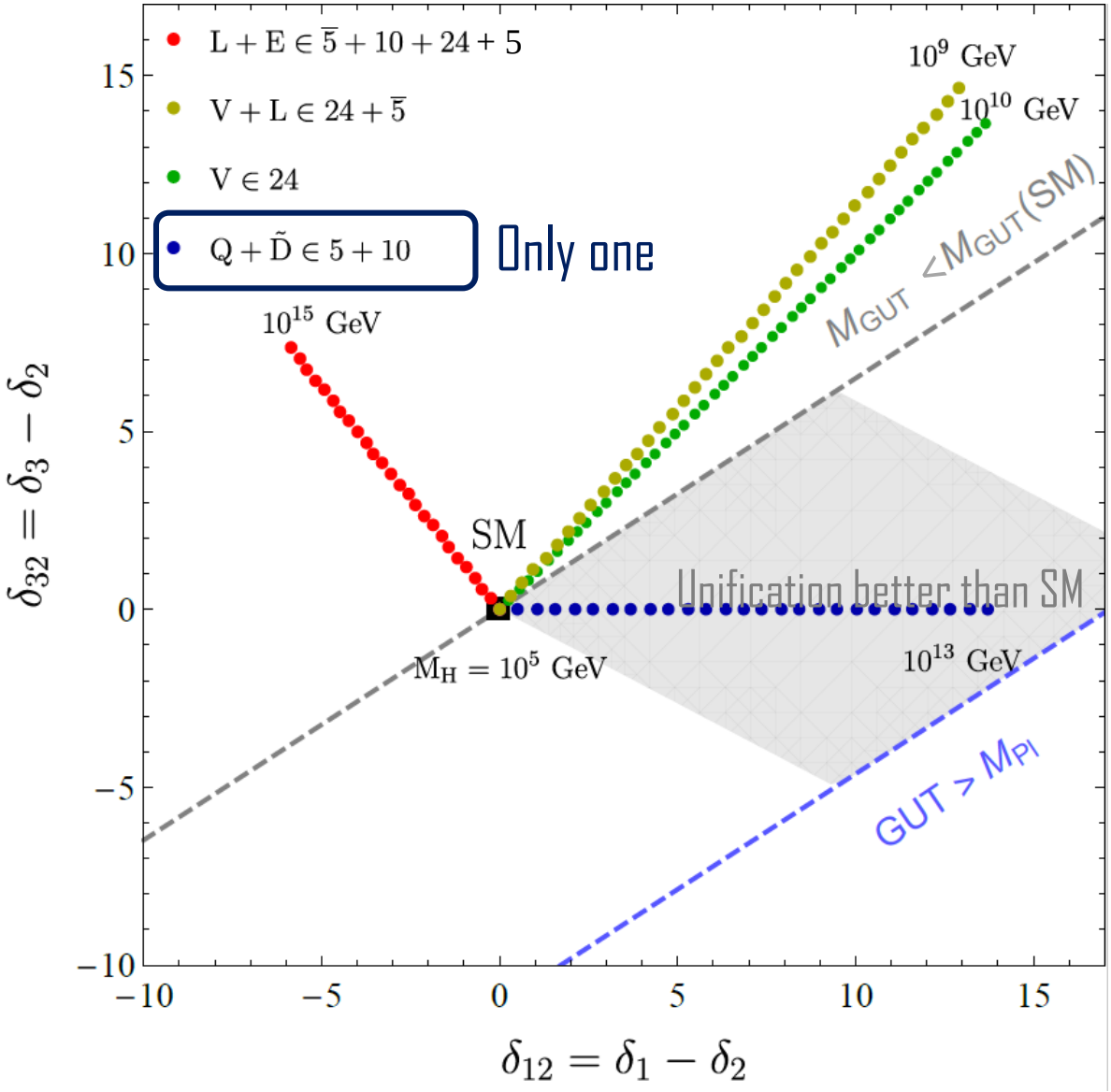


NP running contribution to SM couplings

Good models?

Bottaro, Contino, SV [To Appear]

$SU(3)_{DC}$



$$L = (1,2)_{-1/2}$$
$$E = (1,1)_{1}$$
$$V = (1,3)_{0}$$
$$Q = (3,2)_{1/6}$$
$$\tilde{D} = (\bar{3},1)_{1/3}$$

Arxiv: 1612.05638