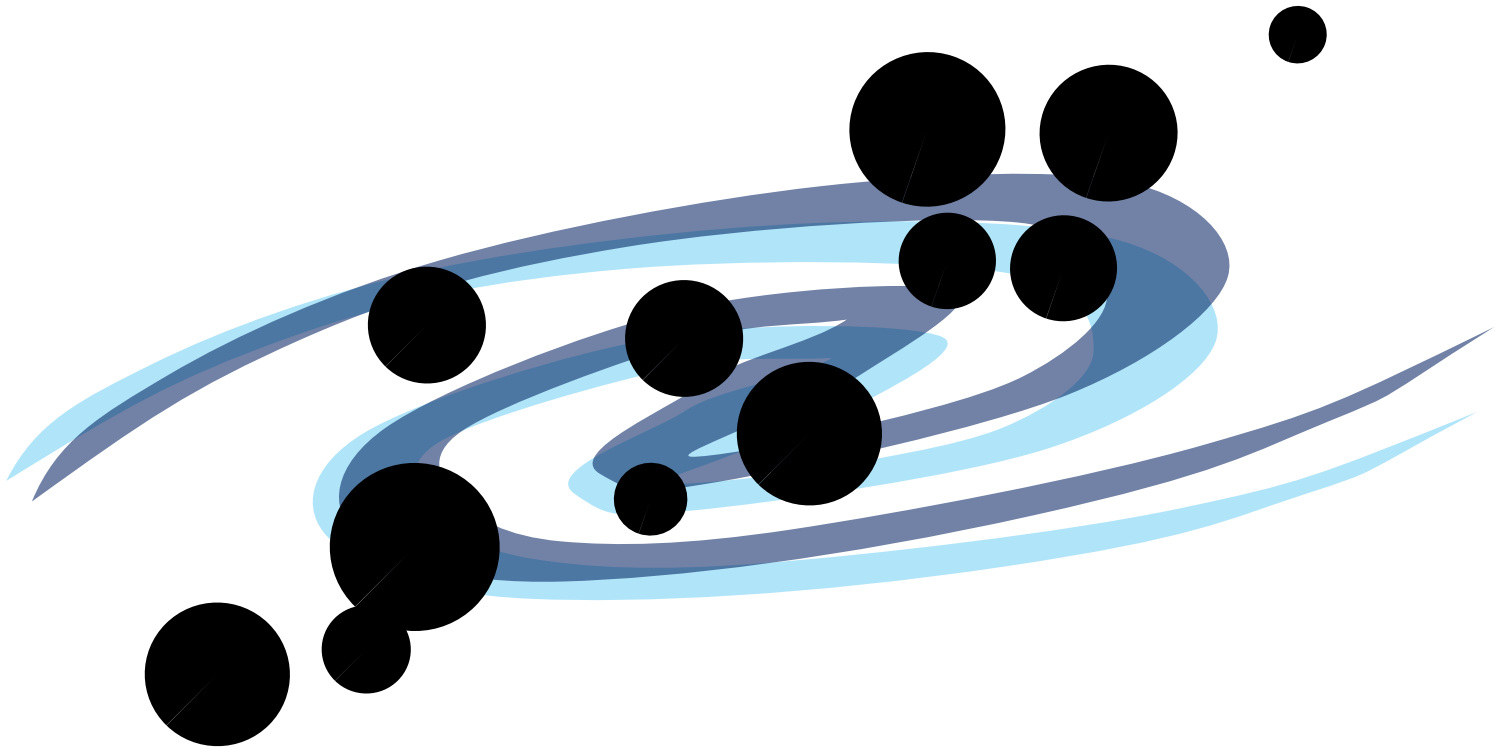
COMPOSITE DM AND COLLIDER PHENOMENOLOGY

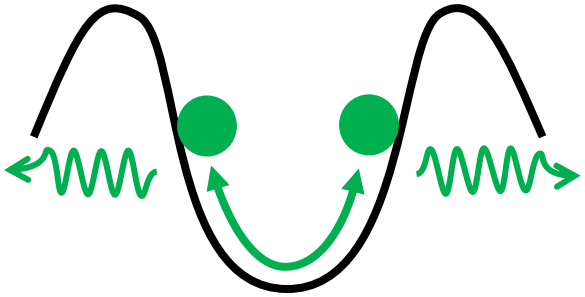
Lingfeng Li
李凌风
ICTP-AP, UCAS



Nov. 2 2025
The 5th QFT Workshop
Beijing

25xx.abcde H-C. Cheng, X. Jiang, LFL, E. Salvioni

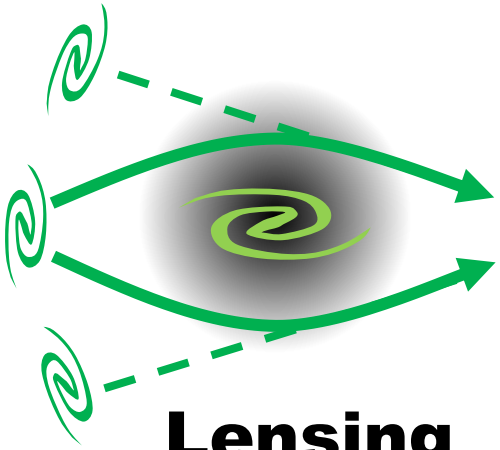
See also Jianghao Yu's talk



CMB Power Spectra

Large Scale Structure

Galaxy Formation



Lensing

Hydrodynamic effects on the filtered dark matter produced by a first-order phase transition

#11

Siyu Jiang (Zhongshan U., Zhuhai), Fa Peng Huang (Zhongshan U., Zhuhai), Chong Sheng Li (Peking U., CHEP and Peking U., SKLNPT) (May 3, 2023)

Published in: *Phys.Rev.D* 108 (2023) 6, 063508 • e-Print: 2305.02218 [hep-ph]

pdf DOI cite claim reference search 14 citations

Complementary probe of dark matter blind spots by lepton colliders and gravitational waves

#21

Yan Wang (Inner Mongolia Norm. U.), Chong Sheng Li (Peking U. and Peking U., SKLNPT and Peking U., CHEP), Fa Peng Huang (Washington U., St. Louis) (Dec 7, 2020)

Published in: *Phys.Rev.D* 104 (2021) 5, 053004 • e-Print: 2012.03920 [hep-ph]

pdf DOI cite claim reference search 14 citations

A Dark Matter Model with Non-Abelian Gauge Symmetry

#98

Hao Zhang (Peking U. and Peking U., CAPT), Chong Sheng Li (Peking U. and Peking U., CAPT), Qing-Hong Cao (Argonne and Chicago U., EFI), Zhao Li (Peking U. and Peking U., CAPT and Michigan State U.) (Oct, 2009)

Published in: *Phys.Rev.D* 82 (2010) 075003 • e-Print: 0910.2831 [hep-ph]

pdf DOI cite claim reference search 46 citations

A Dark Matter Model with Non-Abelian Gauge Symmetry

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Published in: *Phys.Rev.D* 82 (2010) 075003 • e-Print: 0910.2831 [hep-ph]

pdf DOI cite claim reference search 46 citations

Effective Dark Matter Model: Relic density, CDMS II, Fermi LAT and LHC

#96

Qing-Hong Cao (Argonne and Chicago U., EFI), Chuan-Ren Chen (Tokyo U., IPMU), Chong Sheng Li (Peking U. and Peking U., CAPT), Hao Zhang (Peking U. and Peking U., CAPT and Chicago U., EFI) (Dec, 2009)

Published in: *JHEP* 08 (2011) 018 • e-Print: 0912.4511 [hep-ph]

pdf DOI cite claim reference search 213 citations

Probing the baryogenesis and dark matter relaxed in phase transition by gravitational waves and colliders

#32

Fa Peng Huang (IBS, Daejeon, CTPU), Chong Sheng Li (Peking U. and Peking U., CHEP and Peking U., SKLNPT) (Sep 27, 2017)

Published in: *Phys.Rev.D* 96 (2017) 9, 095028 • e-Print: 1709.09691 [hep-ph]

pdf DOI cite claim reference search 68 citations

Diphoton and dark matter from cascade decay

#39

Fa Peng Huang (Beijing, Inst. High Energy Phys.), Chong Sheng Li (Peking U., SKLNPT and Peking U. and Peking U., CHEP), Ze Long Liu (Peking U. and Peking U., SKLNPT), Yan Wang (Beijing, Inst. High Energy Phys.) (Dec 21, 2015)

Published in: *Phys.Rev.D* 94 (2016) 5, 055025 • e-Print: 1512.06732 [hep-ph]

pdf DOI cite claim reference search 126 citations

Searching for the signal of dark matter and photon associated production at the LHC beyond leading order

#63

Fa Peng Huang (Peking U.), Chong Sheng Li (Peking U. and Peking U., CHEP), Jian Wang (Peking U.), Ding Yu Shao (Peking U.) (Oct, 2012)

Published in: *Phys.Rev.D* 87 (2013) 094018 • e-Print: 1210.0195 [hep-ph]

pdf DOI cite claim reference search 10 citations

Next-to-leading order QCD predictions for the signal of Dark Matter and photon associated production at the LHC

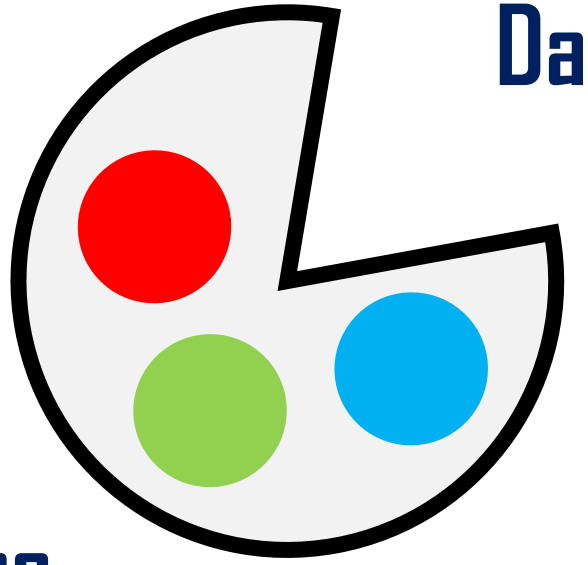
#1

Jian Wang (Peking U. and Peking U., CAPT), Chong Sheng Li (Peking U. and Peking U., CAPT), Ding Yu Shao (Peking U. and Peking U., CAPT), Hao Zhang (Peking U. and Peking U., CAPT) (Jul, 2011)

Published in: *Phys.Rev.D* 84 (2011) 075011 • e-Print: 1107.2048 [hep-ph]

pdf DOI cite claim reference search 14 citations

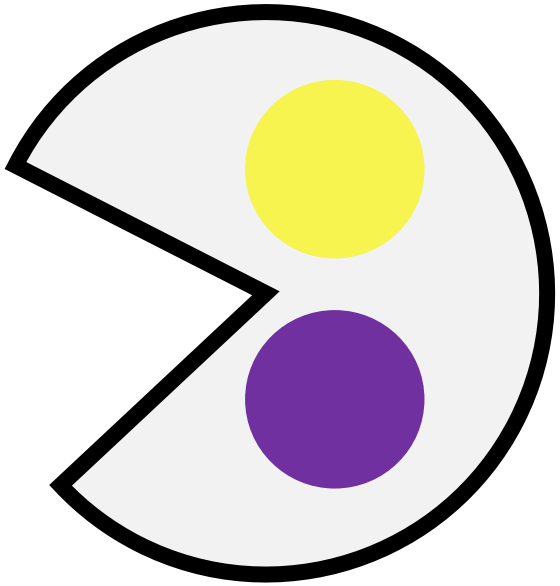
Composite DM Candidates

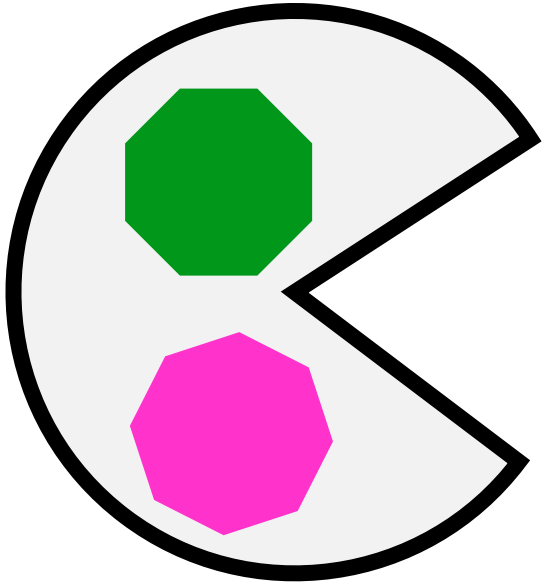


Dark Baryons

Dark Mesons

Dark R-hadrons

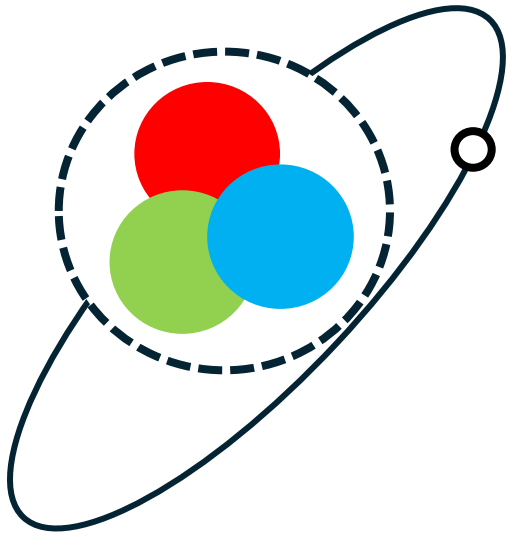




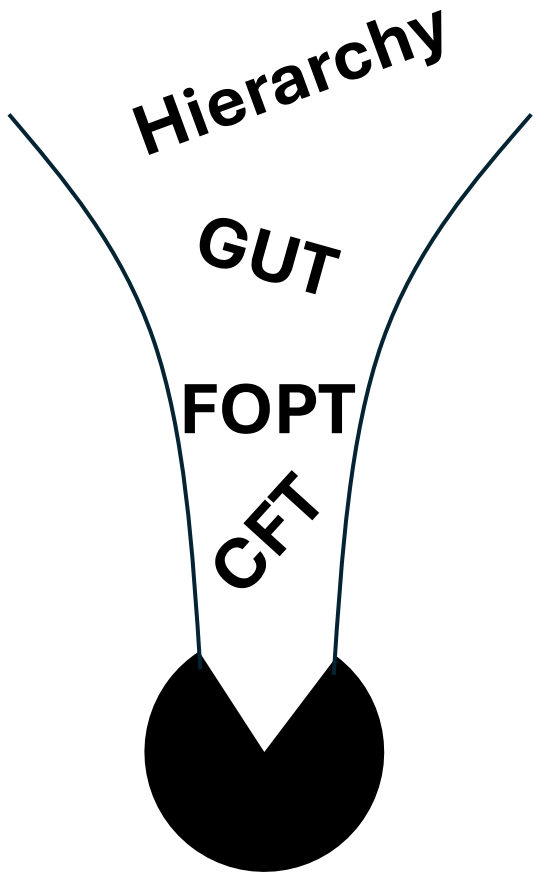
Dark Glueballs

Motivation

"Baryons" are Composite



Z. Chacko, H.S. Goh, and R. Harnik, 0506256; G. Burdman, Z. Chacko, H.S. Goh, R. Harnik, 0609152; H-C. Cheng, LFL, E. Salvioni, and C. Verhaaren, 1803.03561 ……



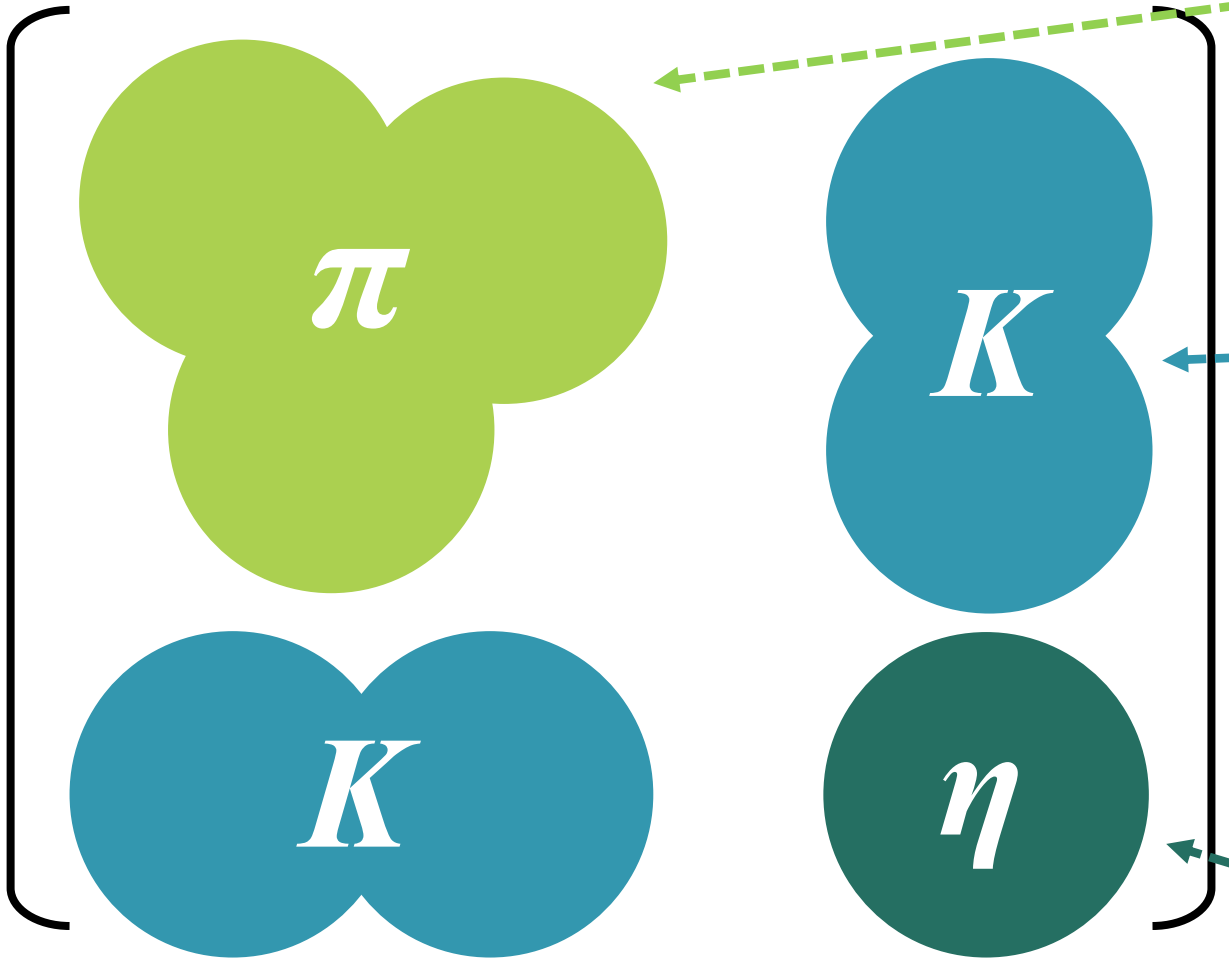
UV Model Building

"Minimal" Setup (?)

Unique Dynamics & Phenomena

P. Schwaller, D. Stolarski, A. Weiler, 1502.05409; CMS, 1810.10069; S. Knapen, J. Shelton, D. Xu, 2103.01238; S. Born, R. Karur, S. Knapen, J. Shelton, 2303.04167; J. Carrosco, J. Zirita, 2307.04847 ……

Back in the SM



"Stable" due to SU(2) isospin symmetry

"Stable" due to strange number conservation

No protection, unstable

Thermal Mechanisms

The messenger: heavy meson that decays, contact with the SM

The DM meson, non-interacting

The intermediate, exists in many models

Y. Hochberg, E. Kuflik, H. Murayama, T. Volansky, J. Wacker, 1411.3727; A. Katz, E. Salvioni, and B. Shakya, 2006.15148……

SIMP-like

Pairwise

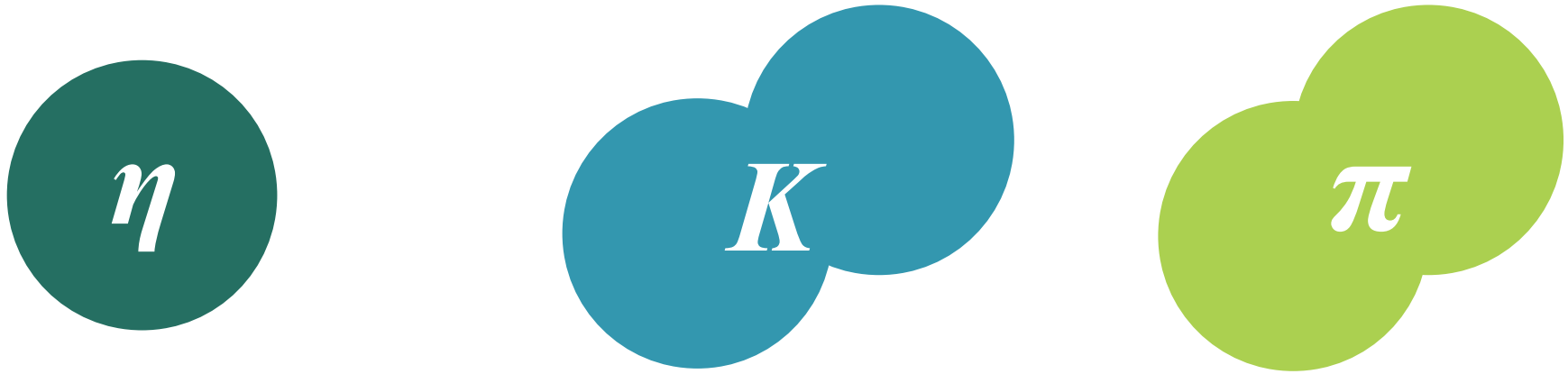
Scattering

The Model

Gauge group: $SO(N_c) \quad N_c \geq 4$

$$SU(3)/SO(3) \Longrightarrow$$ 5 Goldstone bosons

Two π, two K and one η



$m_\eta = (1+\Delta_\eta)\, m_\pi >$ $m_K = (1+\Delta_K)\, m_\pi >$ m_π

Leading ChPT Lagrangian (Low Temp)

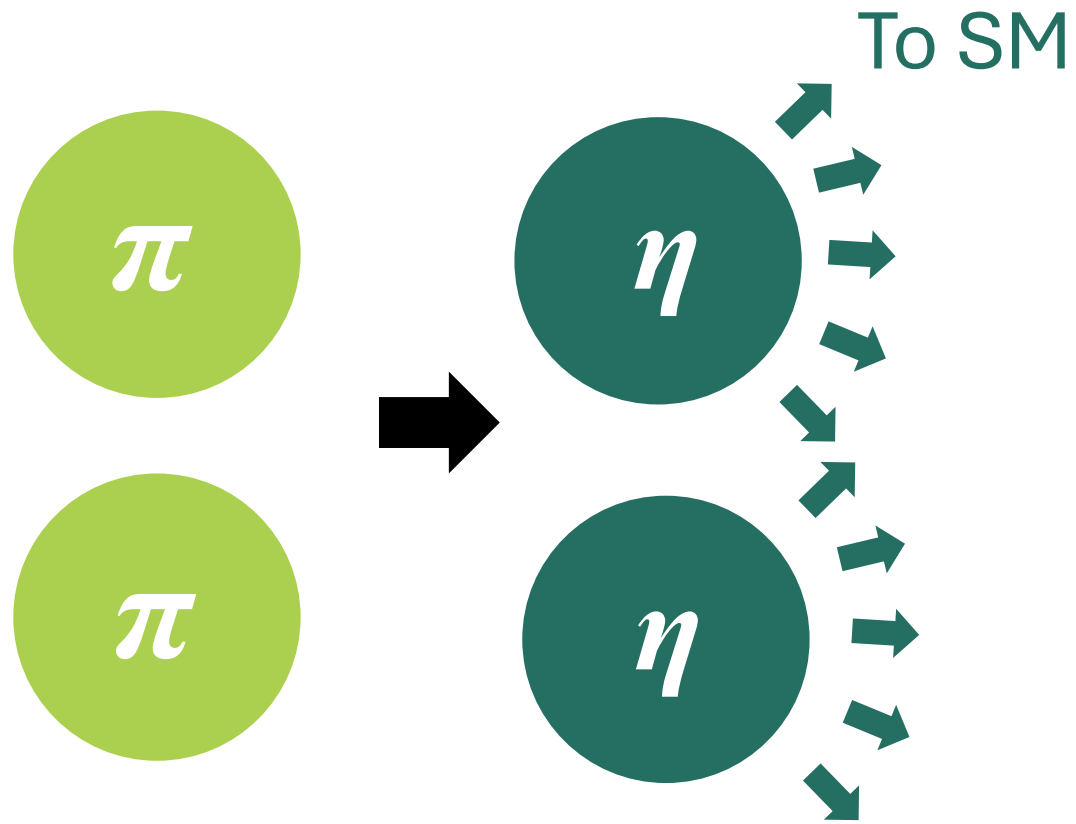
$$
\begin{aligned}
\mathcal{L}_2 \supset\ & \frac{1}{24f^2}\Big\{m_{\hat{\pi}}^2\Big[\hat{\eta}_0^2+2\hat{\pi}_+\hat{\pi}_-+2\hat{K}_{+1/2}\hat{K}_{-1/2}\Big]^2+2(m_{\hat{K}}^2-m_{\hat{\pi}}^2)\Big[\frac{8}{9}\hat{\eta}_0^4+3\hat{\eta}_0^2\hat{K}_{+1/2}\hat{K}_{-1/2}\\
&-\sqrt{\frac{2}{3}}(\hat{\eta}_0\hat{K}_{+1/2}^2\hat{\pi}_-+\hat{\eta}_0\hat{K}_{-1/2}^2\hat{\pi}_+)+2\hat{K}_{+1/2}^2\hat{K}_{-1/2}^2+2\hat{K}_{+1/2}\hat{K}_{-1/2}\hat{\pi}_+\hat{\pi}_-\Big]\Big\}\\
&+\frac{1}{24f^2}\Big\{4(\partial\hat{\pi}_+)^2\hat{\pi}_-^2+4\hat{\pi}_+^2(\partial\hat{\pi}_-)^2-8\partial\hat{\pi}_+\hat{\pi}_+\partial\hat{\pi}_-\hat{\pi}_-+(\partial\hat{K}_{+1/2})^2\hat{K}_{-1/2}^2+\hat{K}_{+1/2}^2(\partial\hat{K}_{-1/2})^2\\
&-2\partial\hat{K}_{+1/2}\hat{K}_{+1/2}\partial\hat{K}_{-1/2}\hat{K}_{-1/2}+8\hat{K}_{+1/2}\partial\hat{K}_{-1/2}\hat{\pi}_+\partial\hat{\pi}_-+8\partial\hat{K}_{+1/2}\hat{K}_{-1/2}\partial\hat{\pi}_+\hat{\pi}_-\\
&-4\hat{K}_{+1/2}\hat{K}_{-1/2}\partial\hat{\pi}_+\partial\hat{\pi}_--4\hat{K}_{+1/2}\partial\hat{K}_{-1/2}\partial\hat{\pi}_+\hat{\pi}_--4\partial\hat{K}_{+1/2}\hat{K}_{-1/2}\hat{\pi}_+\partial\hat{\pi}_-\\
&-4\partial\hat{K}_{+1/2}\partial\hat{K}_{-1/2}\hat{\pi}_+\hat{\pi}_--6\hat{\eta}_0^2\partial\hat{K}_{+1/2}\partial\hat{K}_{-1/2}-6(\partial\hat{\eta}_0)^2\hat{K}_{+1/2}\hat{K}_{-1/2}\\
&+6\hat{\eta}_0\partial\hat{\eta}_0\partial\hat{K}_{+1/2}\hat{K}_{-1/2}+6\hat{\eta}_0\partial\hat{\eta}_0\hat{K}_{+1/2}\partial\hat{K}_{-1/2}+2\sqrt{6}\Big[\partial\hat{\eta}_0\partial\hat{K}_{-1/2}\hat{K}_{-1/2}\hat{\pi}_+\\
&+\partial\hat{\eta}_0\partial\hat{K}_{+1/2}\hat{K}_{+1/2}\hat{\pi}_--\partial\hat{\eta}_0\hat{K}_{+1/2}^2\partial\hat{\pi}_--\partial\hat{\eta}_0\hat{K}_{-1/2}^2\partial\hat{\pi}_+-\hat{\eta}_0(\partial\hat{K}_{-1/2})^2\hat{\pi}_+\\
&-\hat{\eta}_0(\partial\hat{K}_{+1/2})^2\hat{\pi}_-+\hat{\eta}_0\partial\hat{K}_{-1/2}\hat{K}_{-1/2}\partial\hat{\pi}_++\hat{\eta}_0\partial\hat{K}_{+1/2}\hat{K}_{+1/2}\partial\hat{\pi}_-\Big]\Big\}.
\end{aligned}
$$

Mass & 4-point interaction terms

Forbidden Composite DM

The lightest dark sector particle, the DM

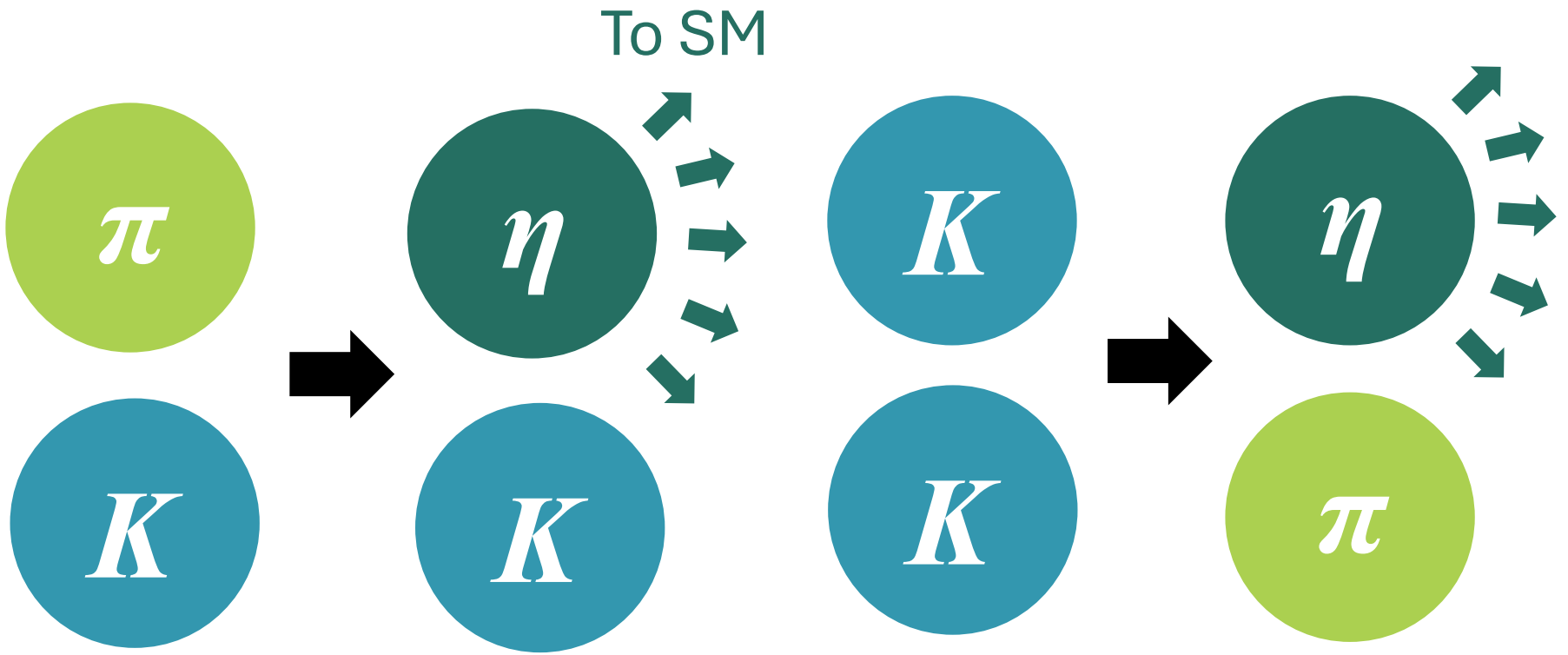
The "excited state", heavier and interacting with the SM



Only energetic particle can go through the mass gap, exponential sensitivity

R.T. D'Agnolo and J.T. Ruderman, 1505.07107; LFL, Y. Tsai, 1901.0993; E. Bernreuther, F. Kahlhoefer, M. Kramer and P. Tunney, 1907.04346……

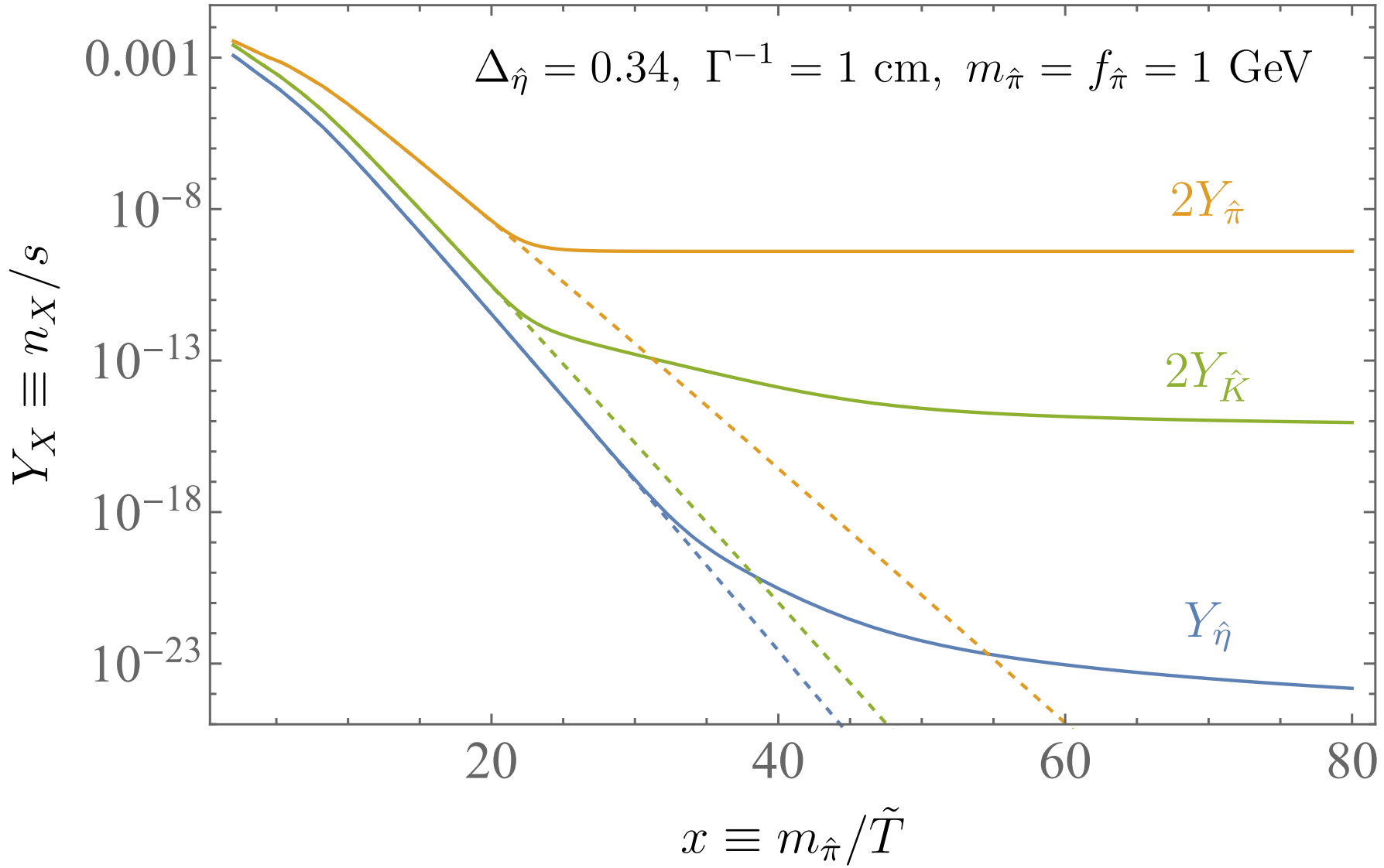
Important Alternative Processes



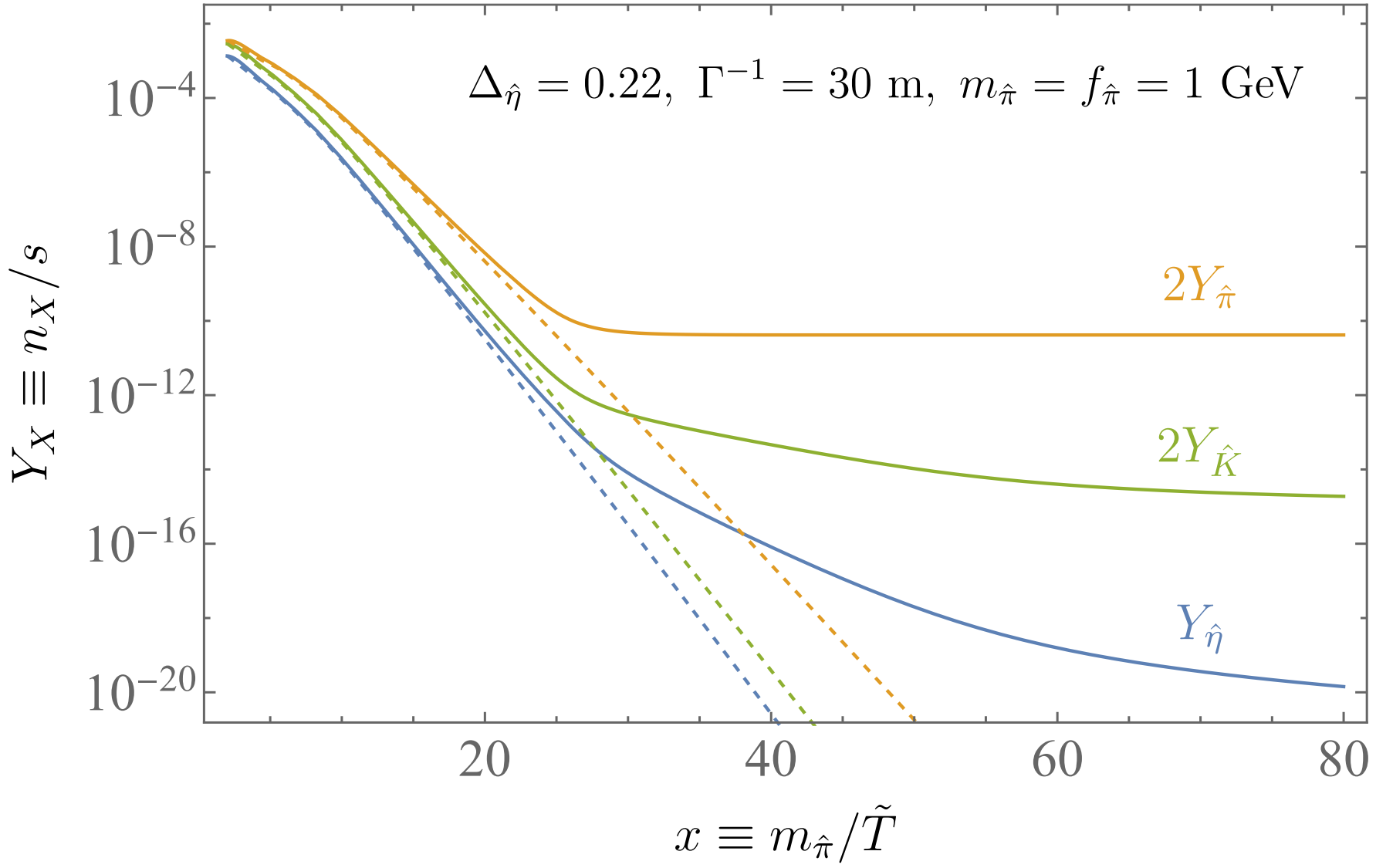
K assisted conversion, low Boltzmann suppression

K annihilation, gives indirect detection signals

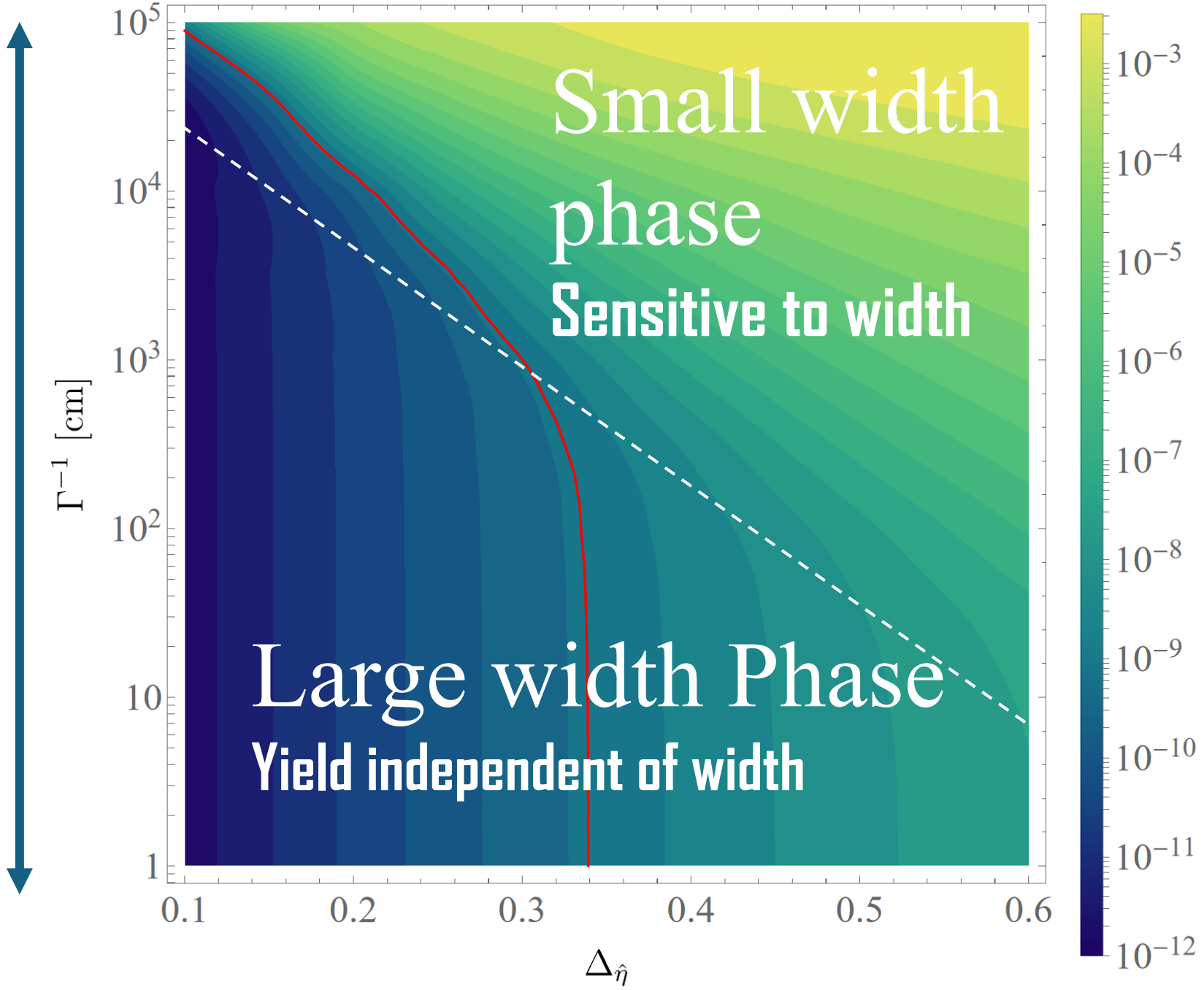
Large Decay Width Limit:
Freezeout Controlled by Conversion



Small Decay Width Limit:
Freezeout Controlled by the Decay



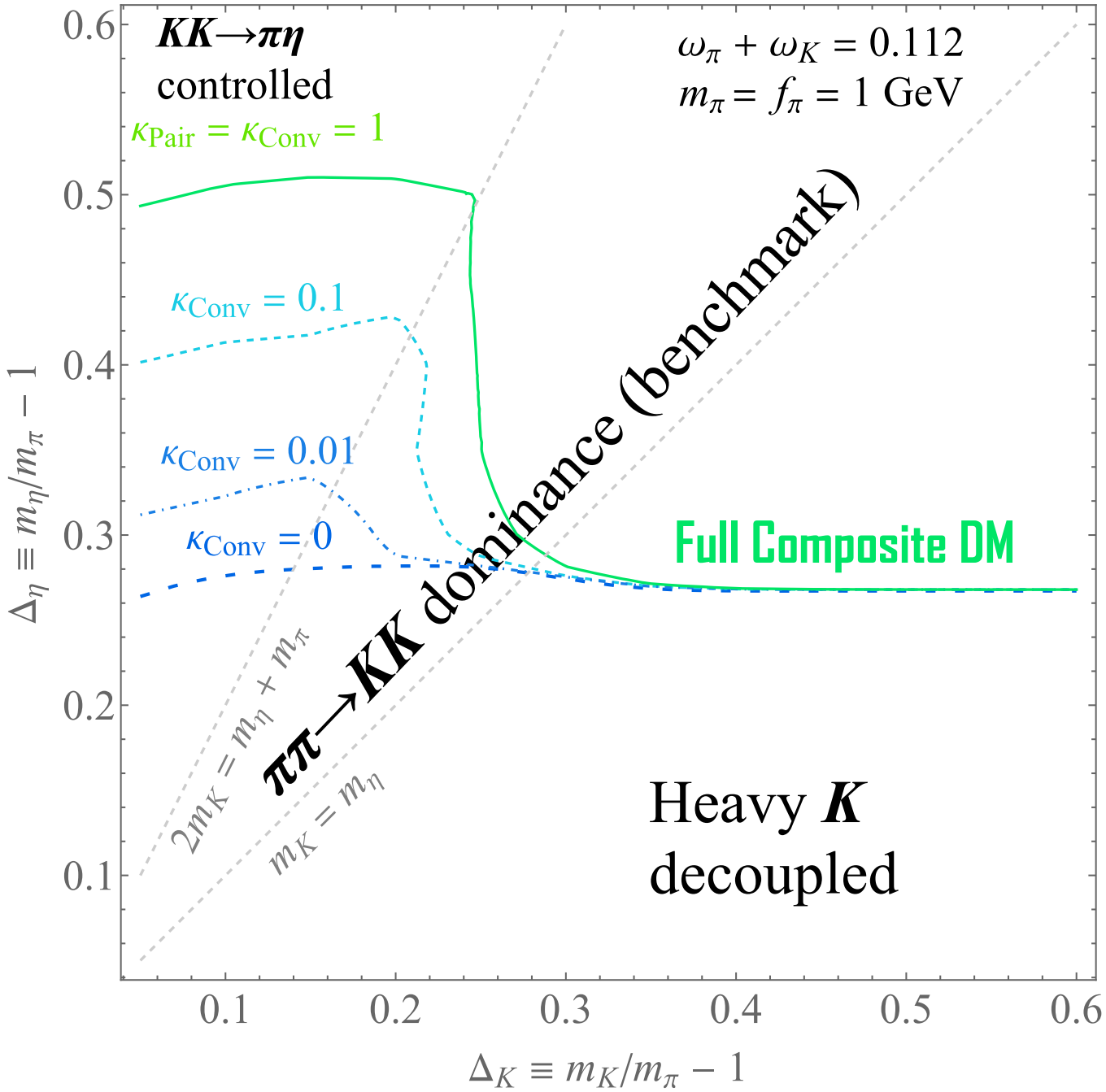
Decay at Human/Lab Length Scales



Extended Phases

At least 3 extra dynamic phases recognized

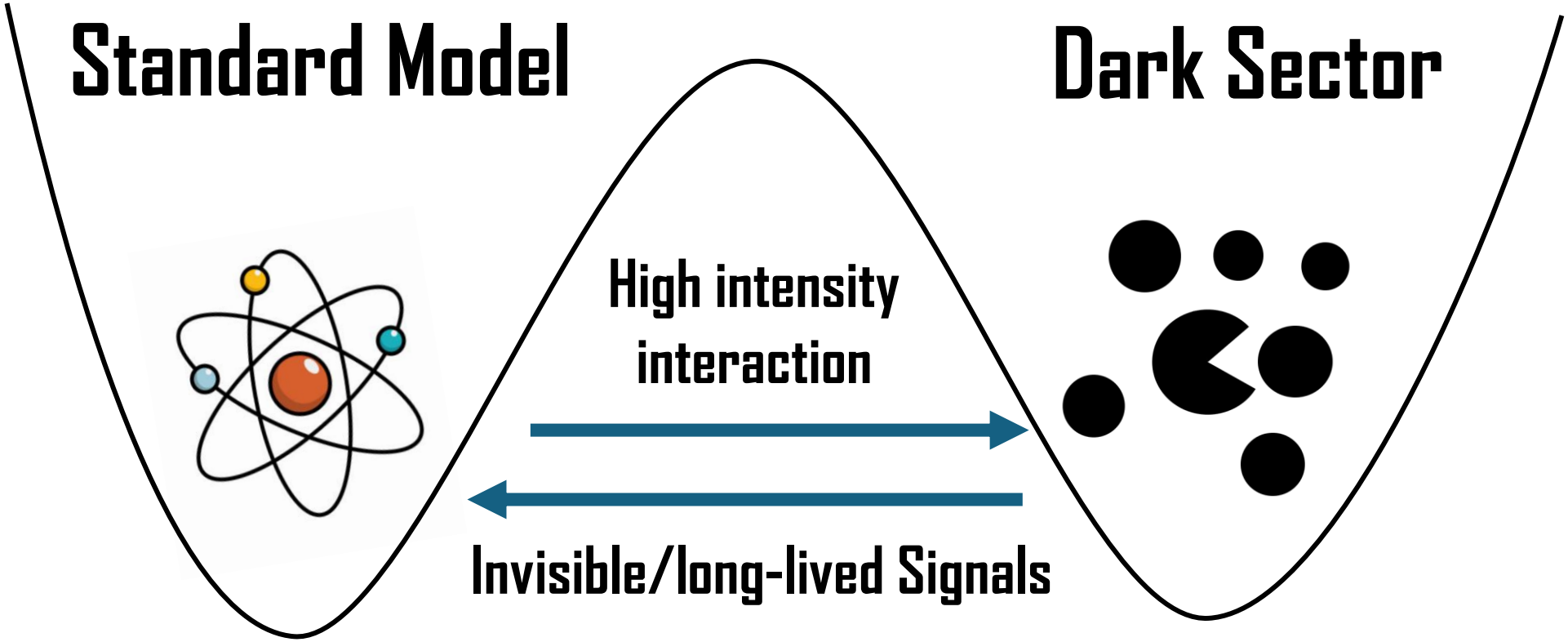
* Assuming all processes having similar cross sections, not necessarily true for realistic models



How to give η a finite lifetime back to the SM?

$\Gamma < 10^{-12}$ GeV

Portal to the Dark Sector



$\epsilon \mathcal{O}_{\mathrm{SM}} J_{\mathrm{Dark}}$ **Relevant portal:** small couplings to keep hidden

$\frac{1}{\Lambda^n} \mathcal{O}_{\mathrm{SM}} J_{\mathrm{Dark}}$ **Irrelevant portal:** Hidden behind EFT

The EW Portal Back to SM

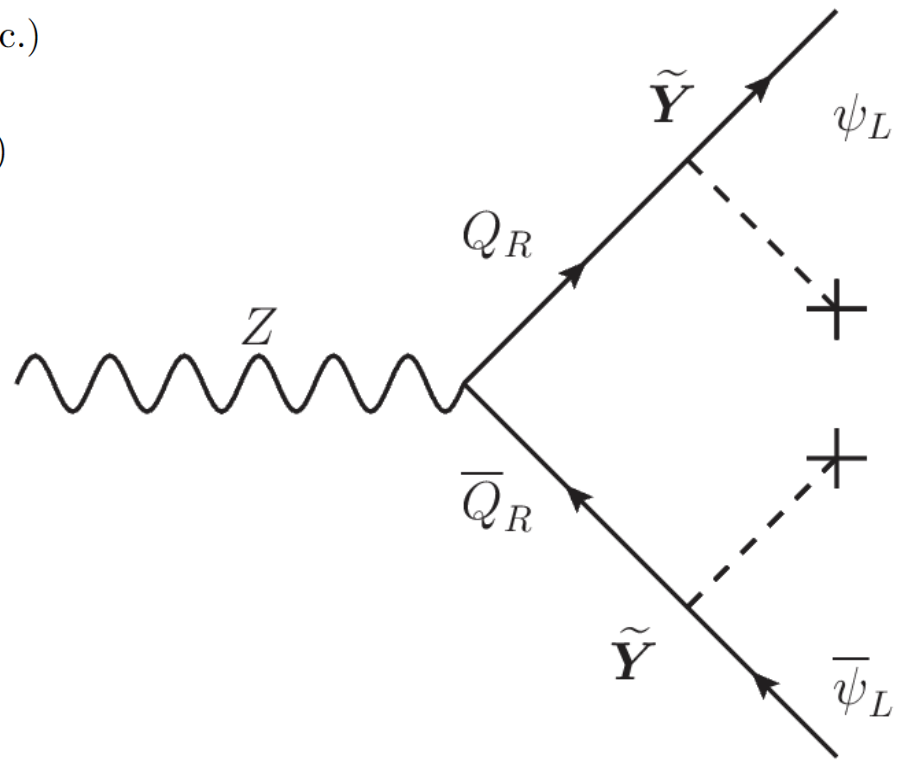
$$-\mathcal{L}_{\rm UV} \supset Q_i^{cT}(M_Q)_{ij}\epsilon Q_j + Q_i^T H Y_{ij}\epsilon\psi_j + Q_i^{cT}\widetilde{H}\widetilde{Y}_{ij}\epsilon\psi_j + \text{h.c.}$$

$$\begin{aligned}\mathcal{L}_{\rm EFT}^{Q+Q^c} =& \frac{1}{2}\left[\left(\frac{|y_1|^2}{M_{Q_1}^2}-\frac{|\tilde{y}_1|^2}{M_{Q_1}^2}\right)(\psi_1^\dagger\bar{\sigma}^\mu\psi_1+\psi_2^\dagger\bar{\sigma}^\mu\psi_2)+\left(\frac{|y_3|^2}{M_{Q_3}^2}-\frac{|\tilde{y}_3|^2}{M_{Q_3}^2}\right)\psi_3^\dagger\bar{\sigma}^\mu\psi_3\right](iH^\dagger D_\mu H+\text{h.c.})\\ &-\left[\frac{y_1\tilde{y}_1}{M_{Q_1}}|H|^2(\psi_1^T\epsilon\psi+\psi_2^T\epsilon\psi_2)+\frac{y_3\tilde{y}_3}{M_{Q_3}}|H|^2(\psi_3^T\epsilon\psi_3)+\text{h.c.}\right] \qquad (4.3)\\ &+|H|^2\left\{\left(\frac{|y_1|^2}{M_{Q_1}^2}+\frac{|\tilde{y}_1|^2}{M_{Q_1}^2}\right)(\psi_1^\dagger i\not{D}\psi_1+\psi_2^\dagger i\not{D}\psi_2)+\frac{|\tilde{y}_3|^2}{M_{Q_3}^2}\psi_3^\dagger i\not{D}\psi_3+\text{h.c.}\right\},\end{aligned}$$

Mass < 1 GeV : decay to $\mu\mu$

Mass > 1 GeV: hadronic decays

$$\Gamma_{\hat{\eta}} \sim \frac{y^4 f_{\hat{\pi}}^2 m_{\hat{\eta}} m_\mu^2}{M_Q^4} \ll \text{GeV}$$



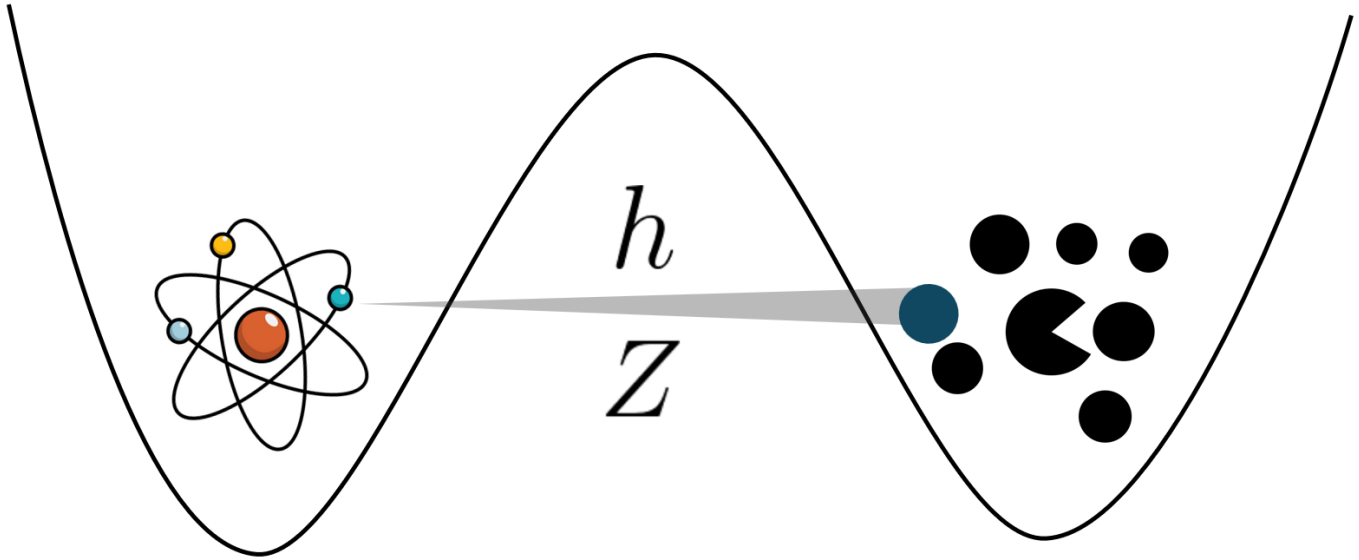
2408.13304 H-C. Cheng, X. Jiang, LFL

2401.08785 H-C. Cheng, X. Jiang, LFL, E. Salvioni

2110.10691 H-C. Cheng, LFL, E. Salvioni

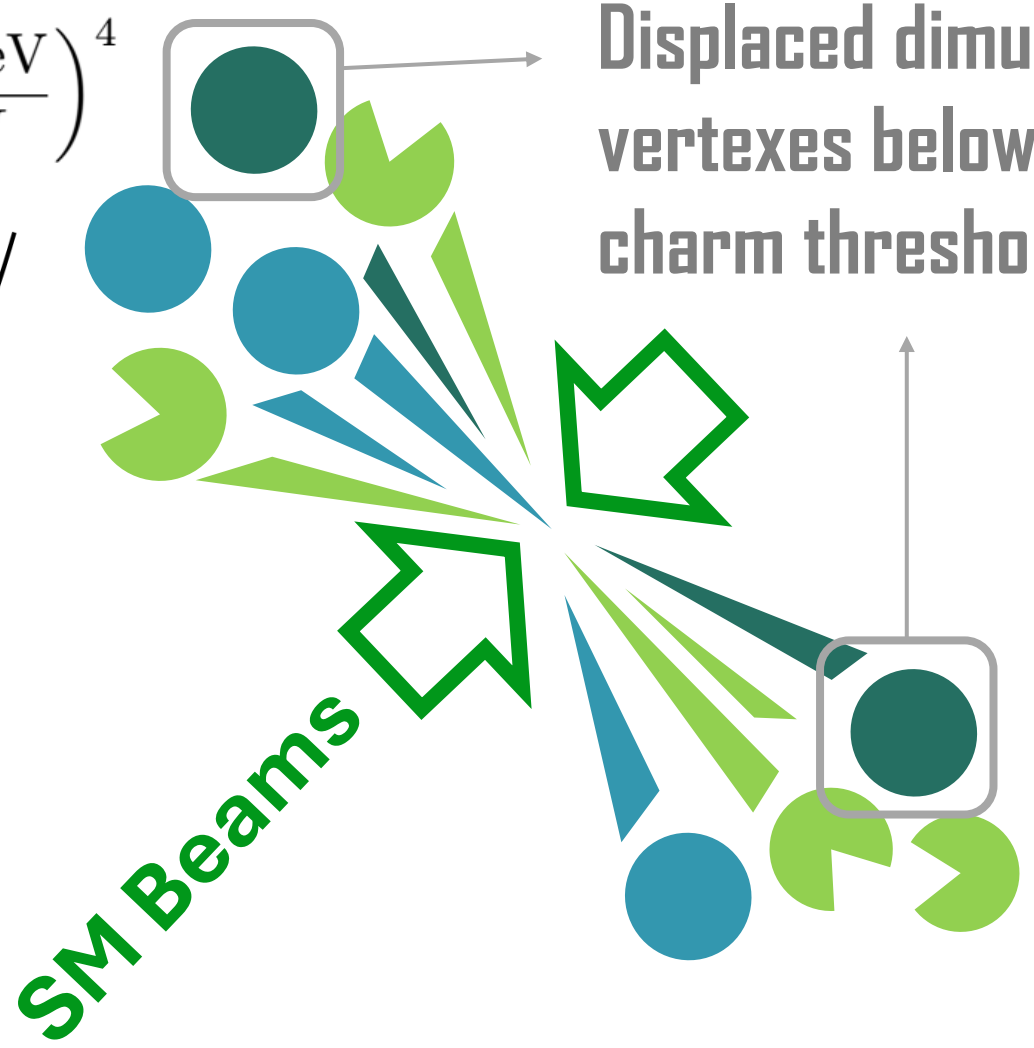
Pheno in the (mid-)UV: Dark Showers & Long-Lived Particles

$$\mathrm{BR}(Z \to \psi'\overline{\psi}') \approx 1.8 \times 10^{-4} \left(\frac{N_d \mathrm{Tr}(\boldsymbol{Y}\boldsymbol{Y}^\dagger\boldsymbol{Y}\boldsymbol{Y}^\dagger)}{3}\right)\left(\frac{1\,\mathrm{TeV}}{M}\right)^4$$

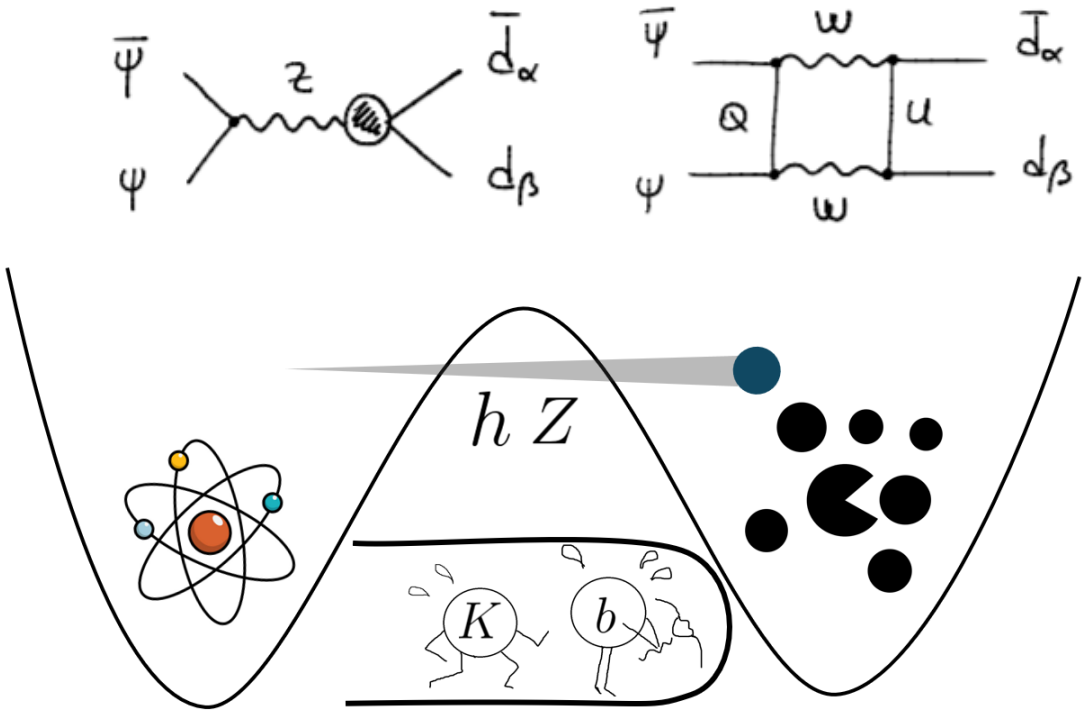


Lead to exotic Higgs and Z decays

Always good to keep an eye on them



The Pheno in the IR: "Flavor Portal" to the Dark Sector



$$\frac{\mathcal{K}}{M^2}(\bar{d}_i\gamma^\mu d_j)(\bar{\psi}\gamma_\mu\psi)$$

$$x_q \equiv m_q^2/M_W^2$$

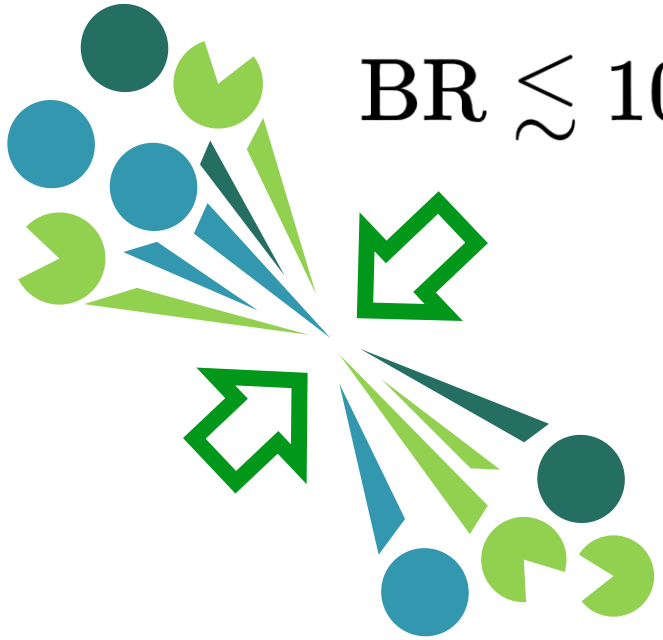
$$\mathcal{K}_q \equiv x_q \log\frac{\Lambda_{\rm UV}^2}{M_W^2} + \frac{-7x_q + x_q^2}{2(1-x_q)} - \frac{4x_q - 2x_q^2 + x_q^3}{(1-x_q)^2}\log x_q$$

$$\mathrm{BR}(B^{+,0} \to \{K^+\hat{\pi}, K^{*0}\hat{\pi}\}) \approx \{0.92, 1.1\} \times 10^{-8} \left(\frac{1\ \mathrm{PeV}}{f_a}\right)^2 \left(\frac{\mathcal{K}_t}{10}\right)^2$$

$$\mathrm{BR}(K^+ \to \pi^+\hat{\pi}) \approx 3.9 \times 10^{-11} \left(\frac{1\ \mathrm{PeV}}{f_a}\right)^2 \left(\frac{\mathcal{K}_t}{10}\right)^2 .$$

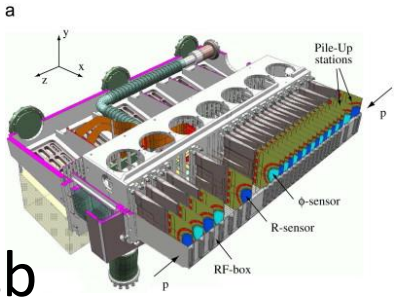
W. Altmannshofer, A. Crivellin, H. Haigh, G. Inguglia and J. Mart Camalich, 2311.14629; J. Martin Camalich, M. Pospelov, P. N. H. Vuong, R. Ziegler and J. Zupan, 2002.04623; M. K. Gaillard, M. B. Gavela, R. Houtz, P. Quilez and R. Del Rey, 1805.06465, T. Li, M.A. Schmidt and M. Yuan, 2506.08342……

Dark Shower (of Z)

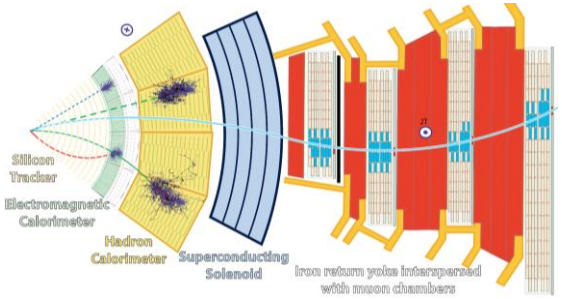


$$\mathrm{BR} \lesssim 10^{-4}$$

Signal: Muon rich jet-like structure with long-lived tracks + MET



LHCb



CMS

Searching for displaced dimuon resonances (one or more) LHCb, 2007.03923; CMS, 2112.13769

CODEX-b

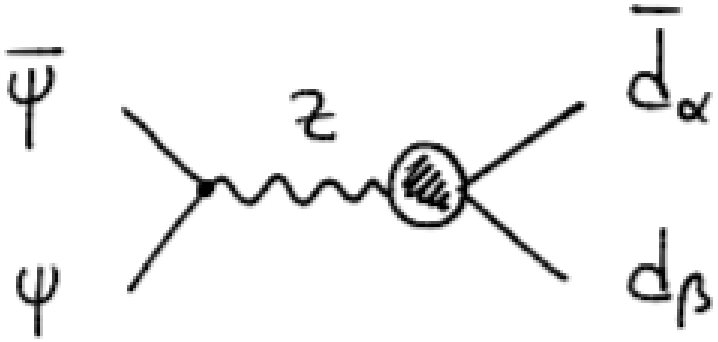
MATHUSLA

FPF Forward Physics Facility

FASER

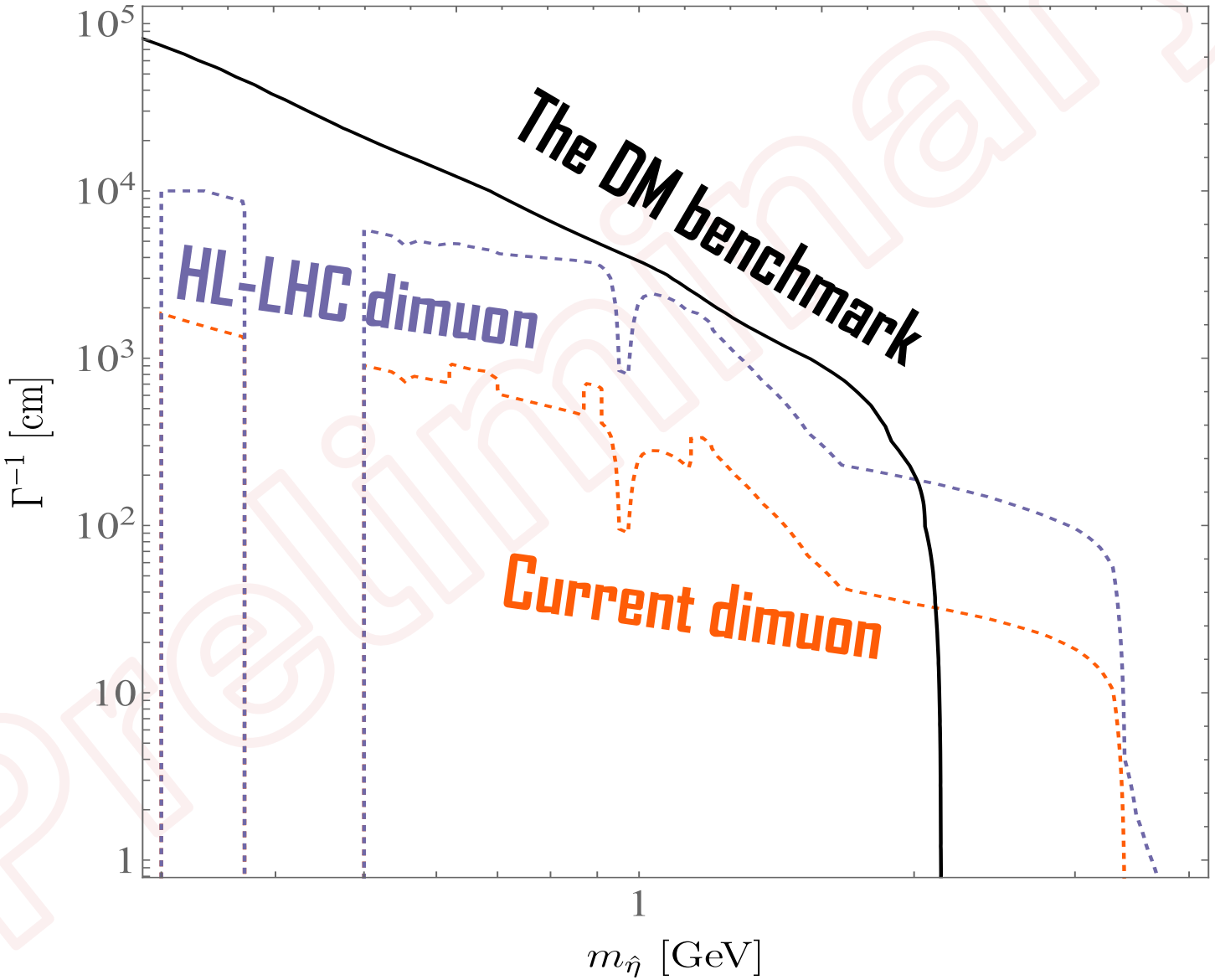
Belle II

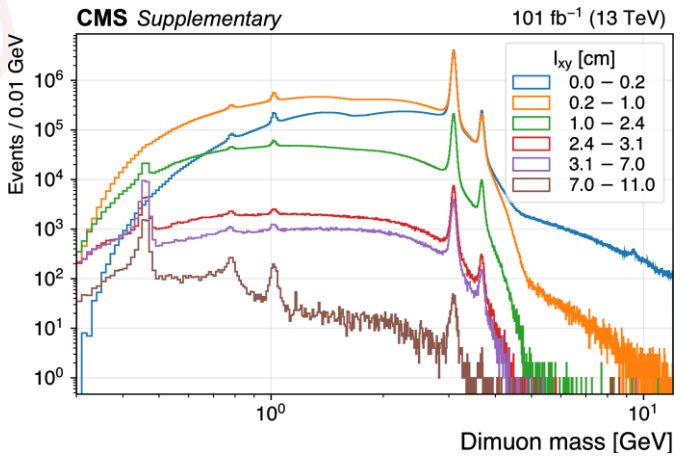
$$\mathrm{BR} \lesssim 10^{-8}$$

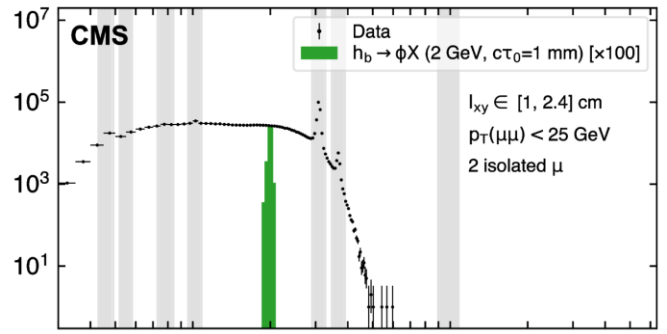


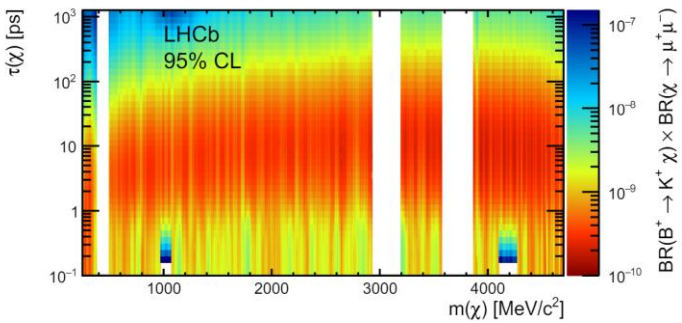
FCNC Decays (of B)

LHC Bounds on Such DM

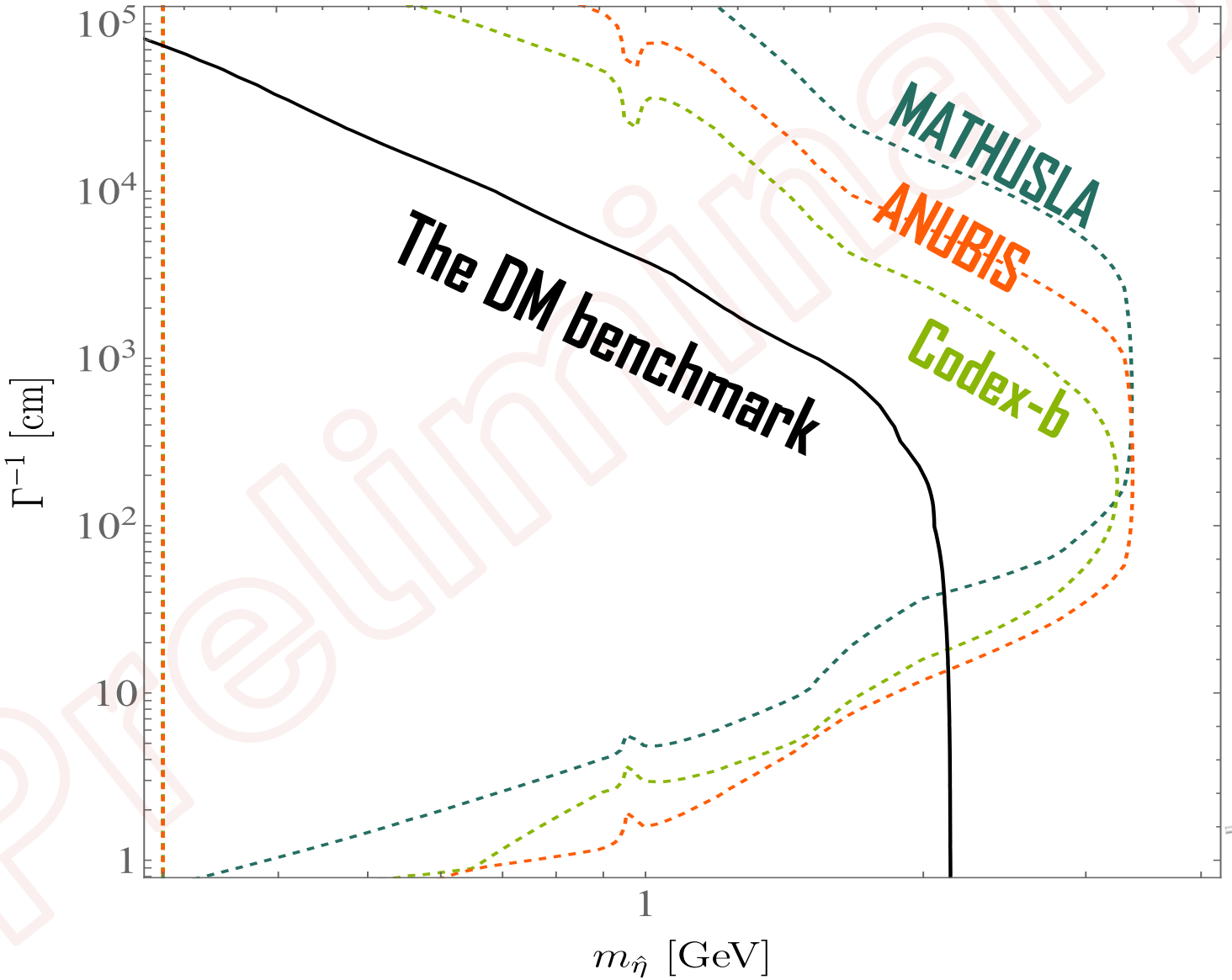


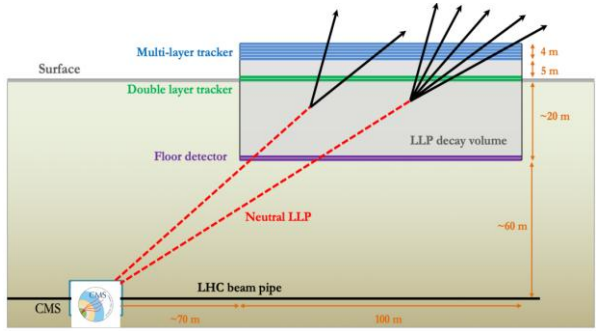


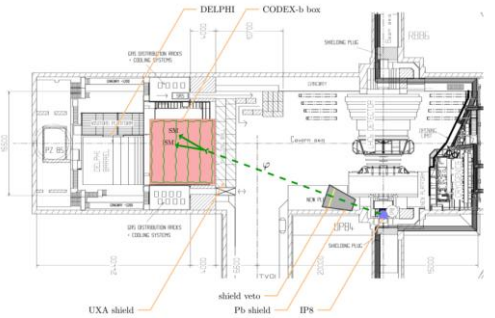


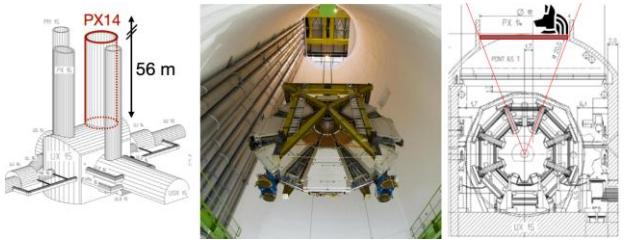


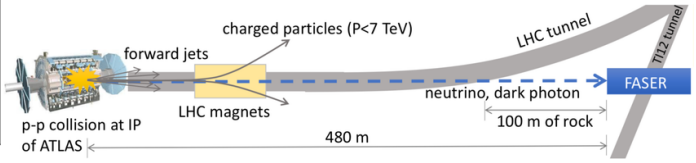
Auxiliary Detectors







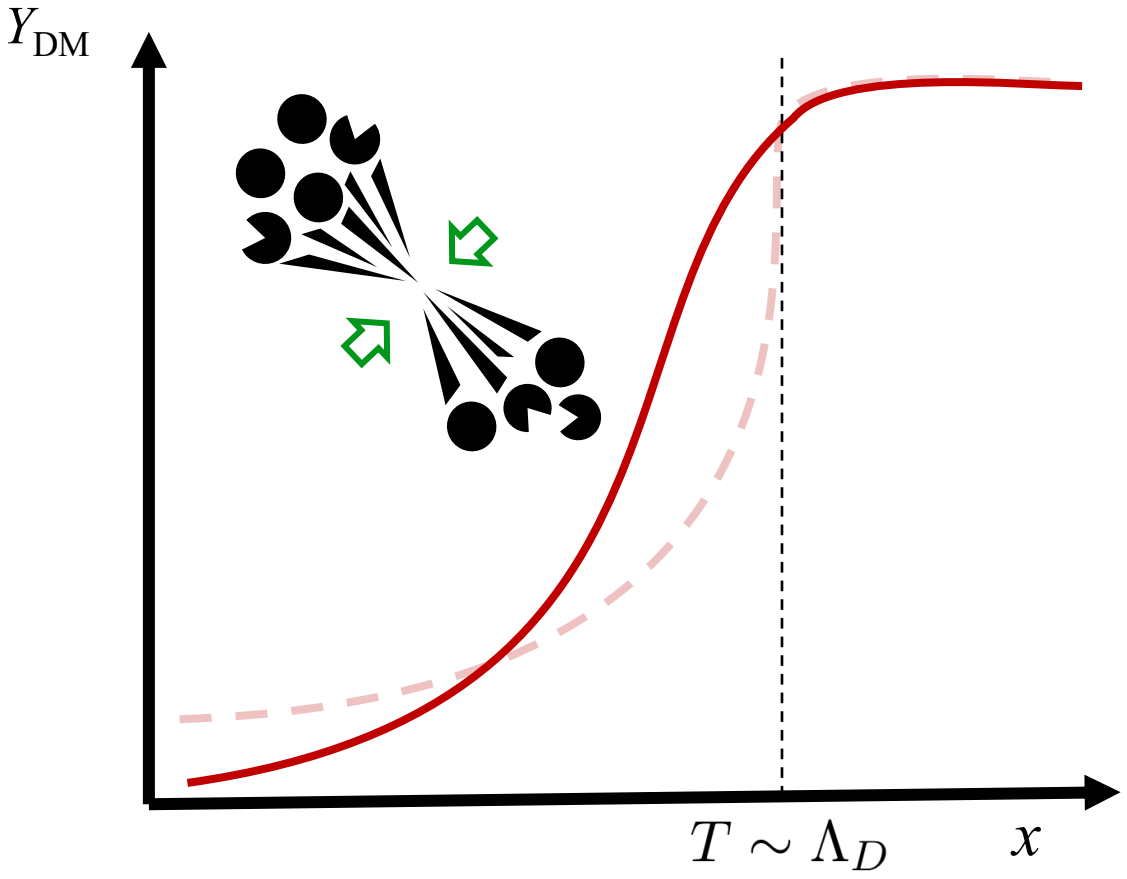




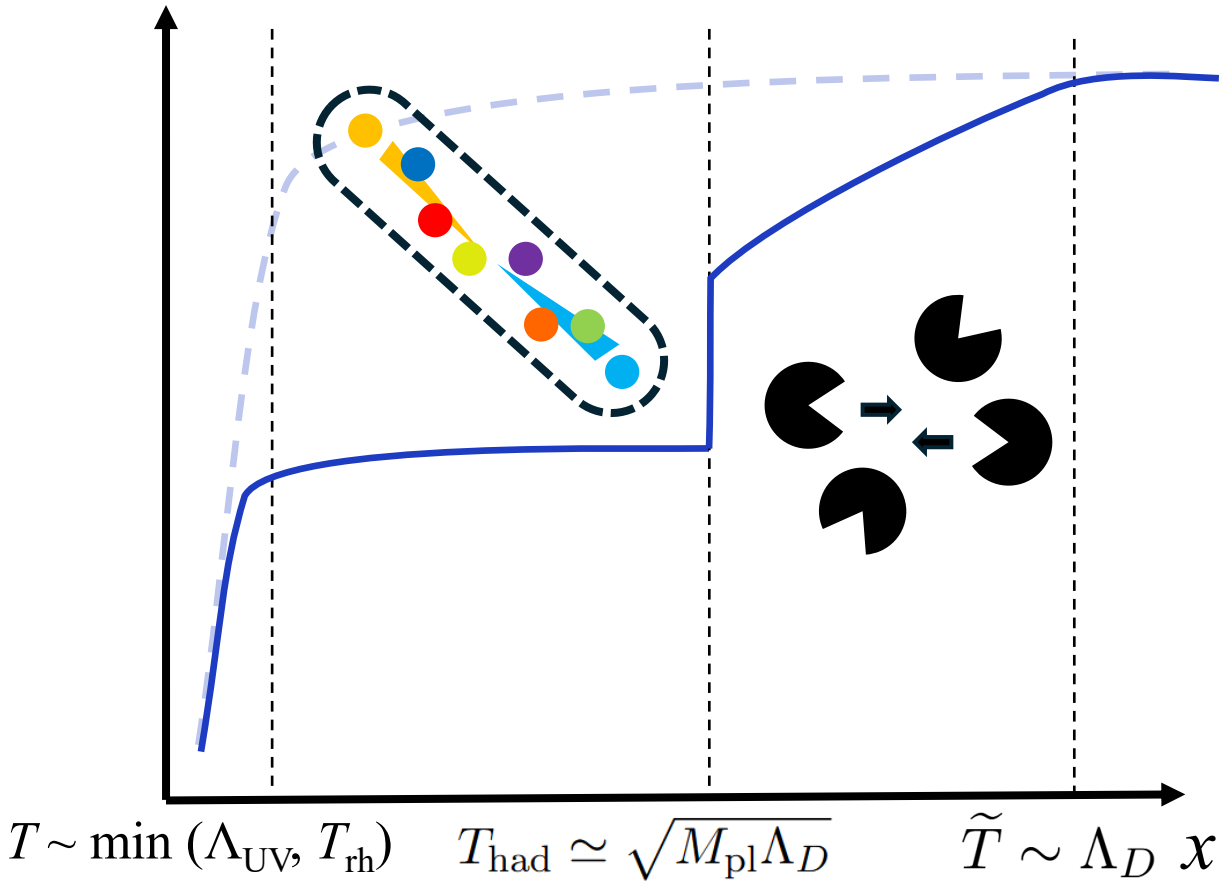
Another Scenario: Composite Freeze-in

LFL, Sida Lu, In preparation

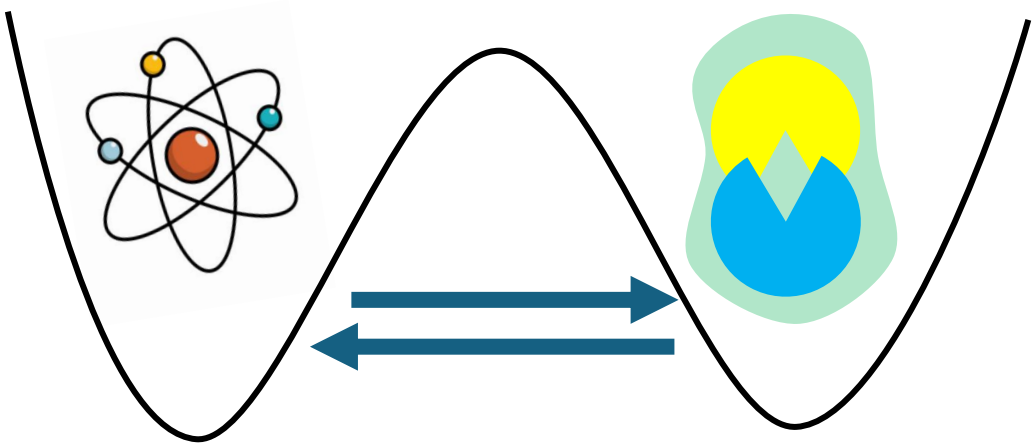
Regular (IR) freeze-in with dark-shower addressed dynamics



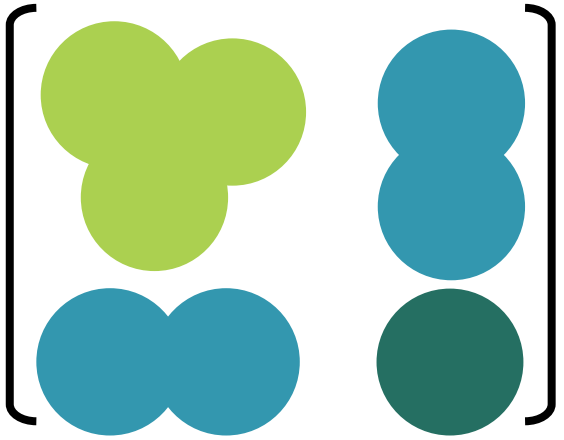
UV freeze-in scenario (could be pure gravitational)



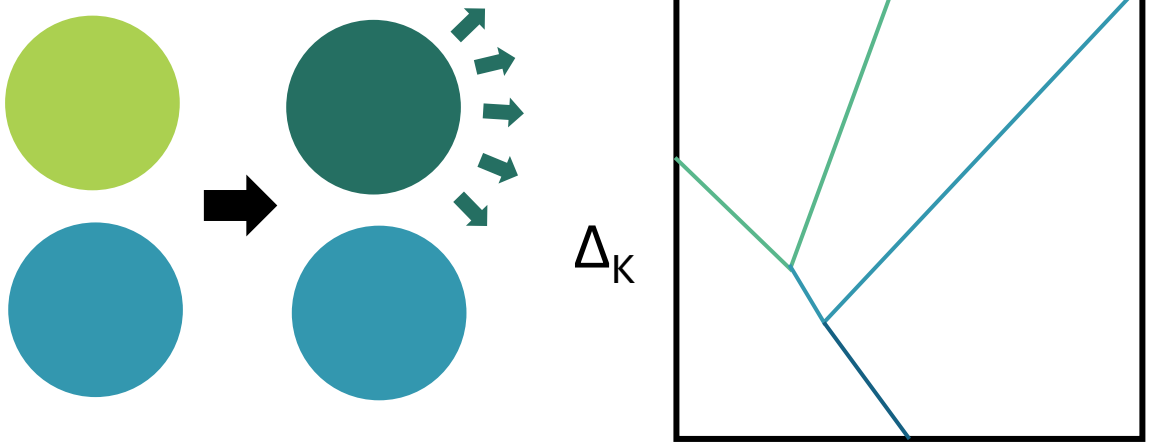
SUMMARY



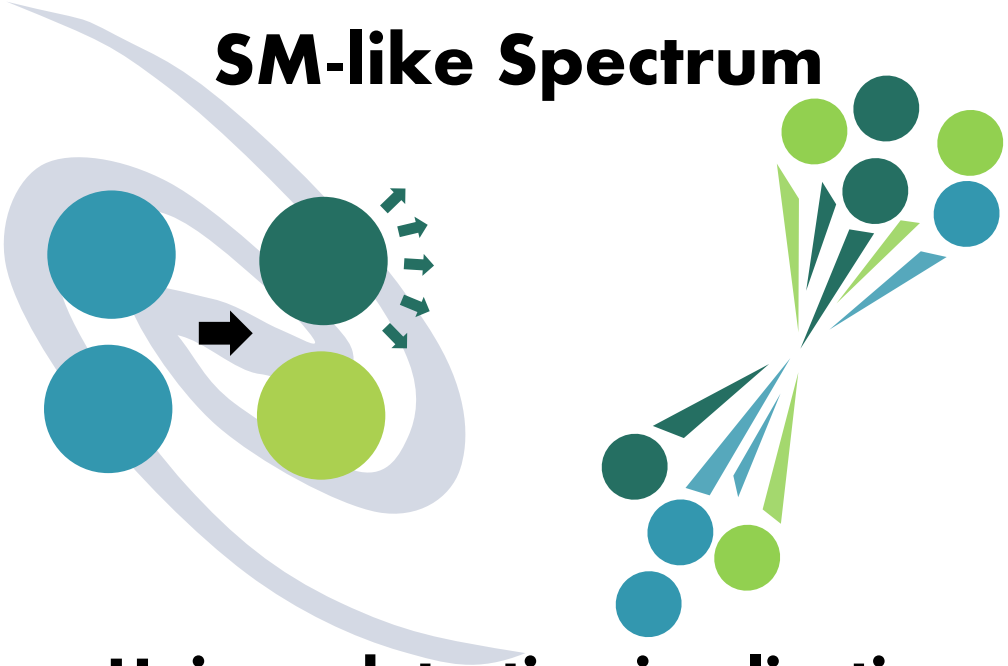
Composite DM with EW Portal



SM-like Spectrum



Many New Dynamics



Unique detection implications

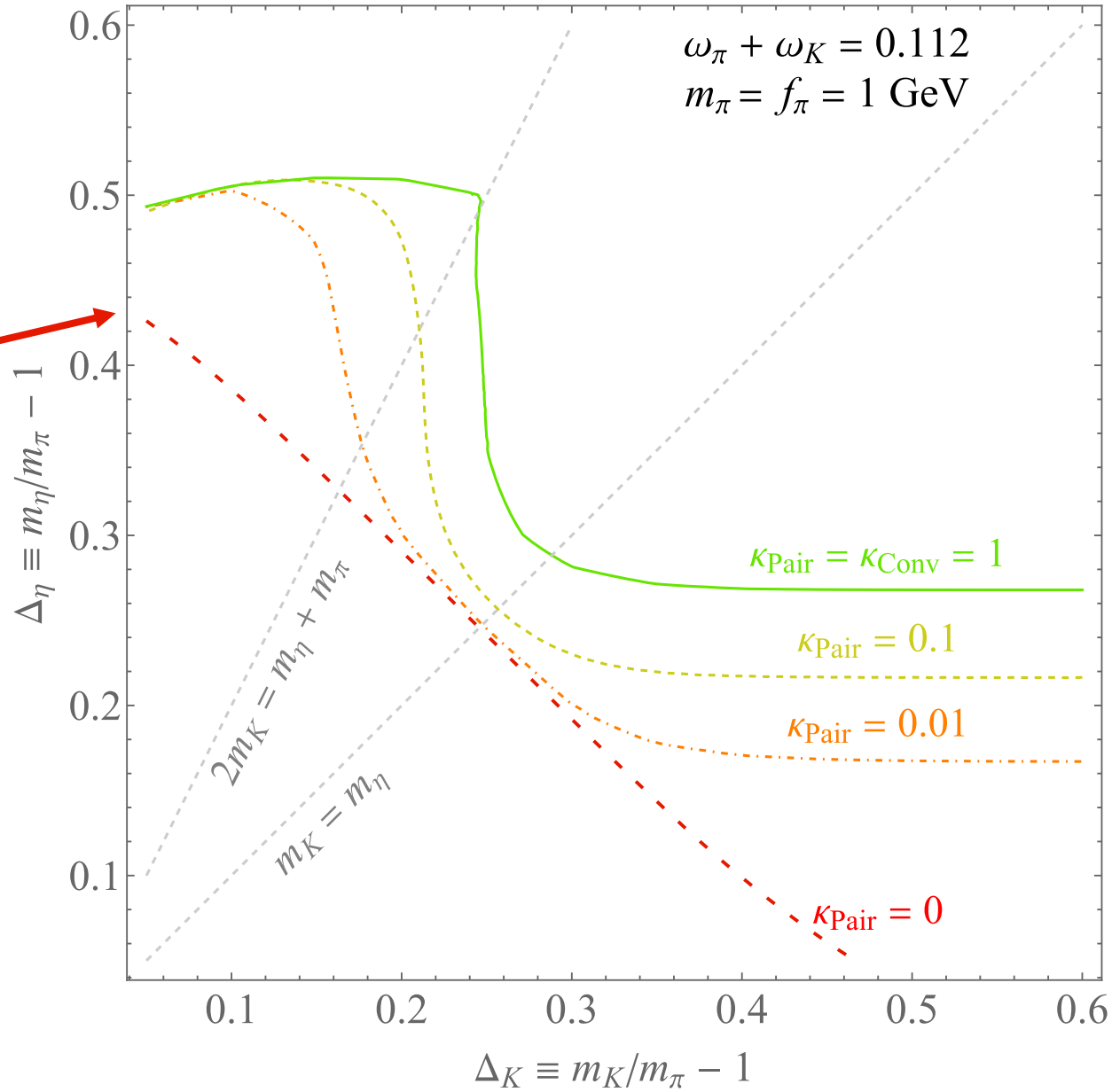
庆贺李重生老师八十华诞

2012 - 2025

一声迟来的祝福.....

真心不改 真英雄

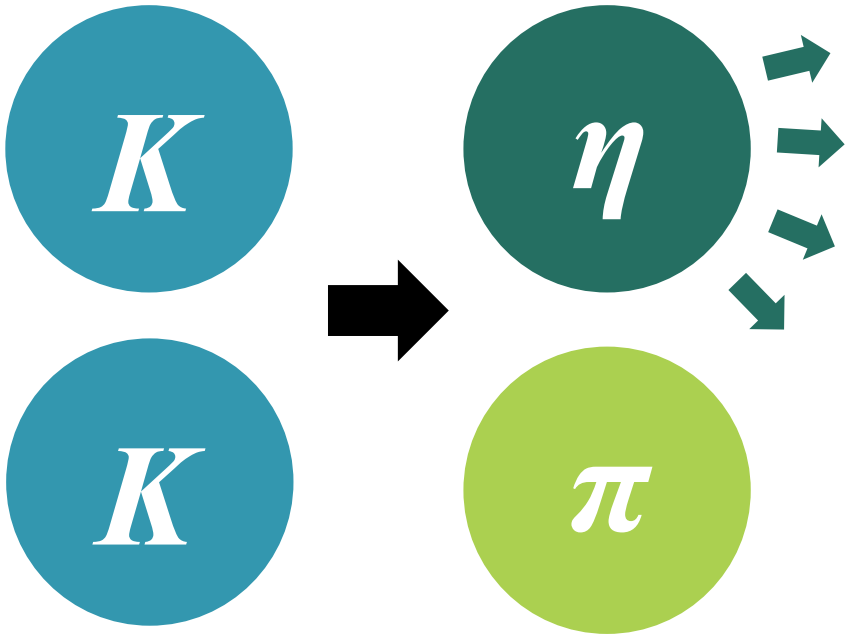
Full $\pi K \to \eta K$ dominance



Indirect Detection Prospects

- As forbidden dark matter, usually free from indirect detection

- The remaining secondary Kaon DM can annihilate to SM, strongly depending on how many K remain

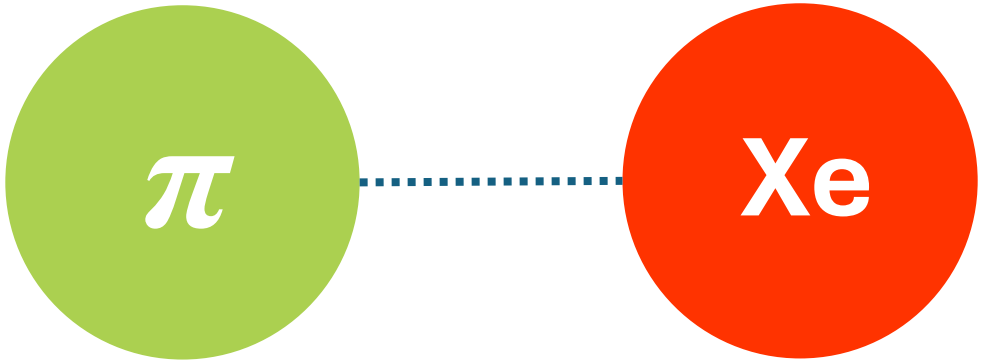


The most stringent CMB spectral distortion limit constraints the highly degenerate case ($\Delta < 1\%$)

Direct Detection Prospects

The leading Z exchange between DM and SM are forbidden by the same symmetry that stabilizes the DM, the remaining Higgs exchange:

$$\mathcal{L} \supset 4B \frac{y_1 \tilde{y}_1}{M_{Q_1}} \pi_+ \pi_- |H|^2 \,,$$



Nucleon scattering Xsec:

$$\simeq 2.5 \times 10^{-45}\,\mathrm{cm}^2\, b^2 \left(\frac{m_N}{m_\pi + m_N}\right)^2 \left(\frac{f}{\mathrm{GeV}}\right)^2 \left(\frac{y_1 \tilde{y}_1}{10^{-2}}\right)^2 \left(\frac{\mathrm{TeV}}{M_{Q_1}}\right)^2$$

When m > 8 GeV , could be above the neutrino fog