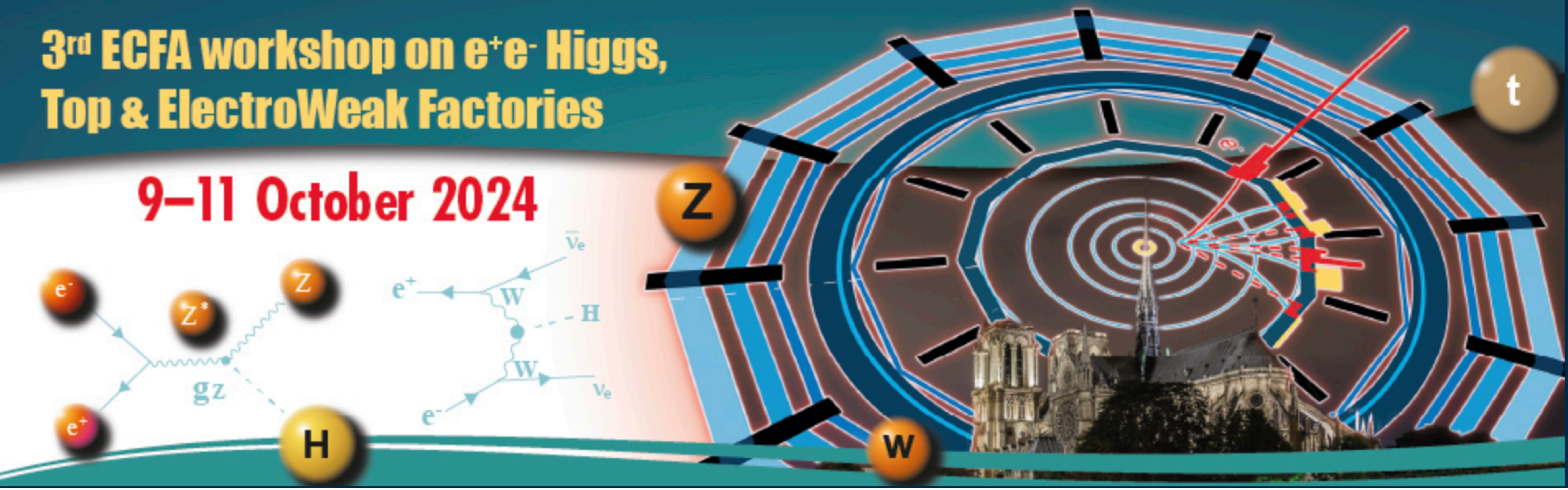

Electroweak Portal Dark Shower

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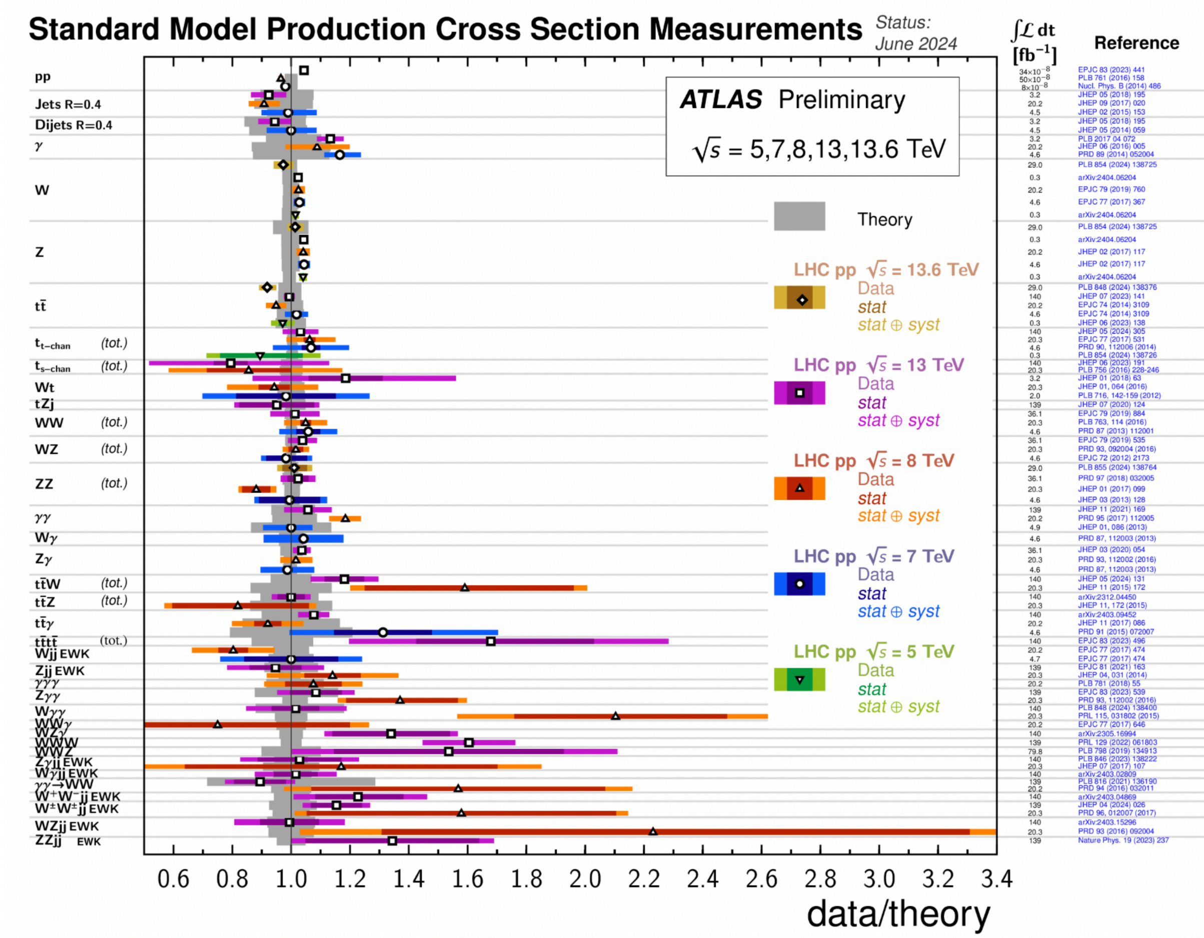
For 3rd ECFA Workshop

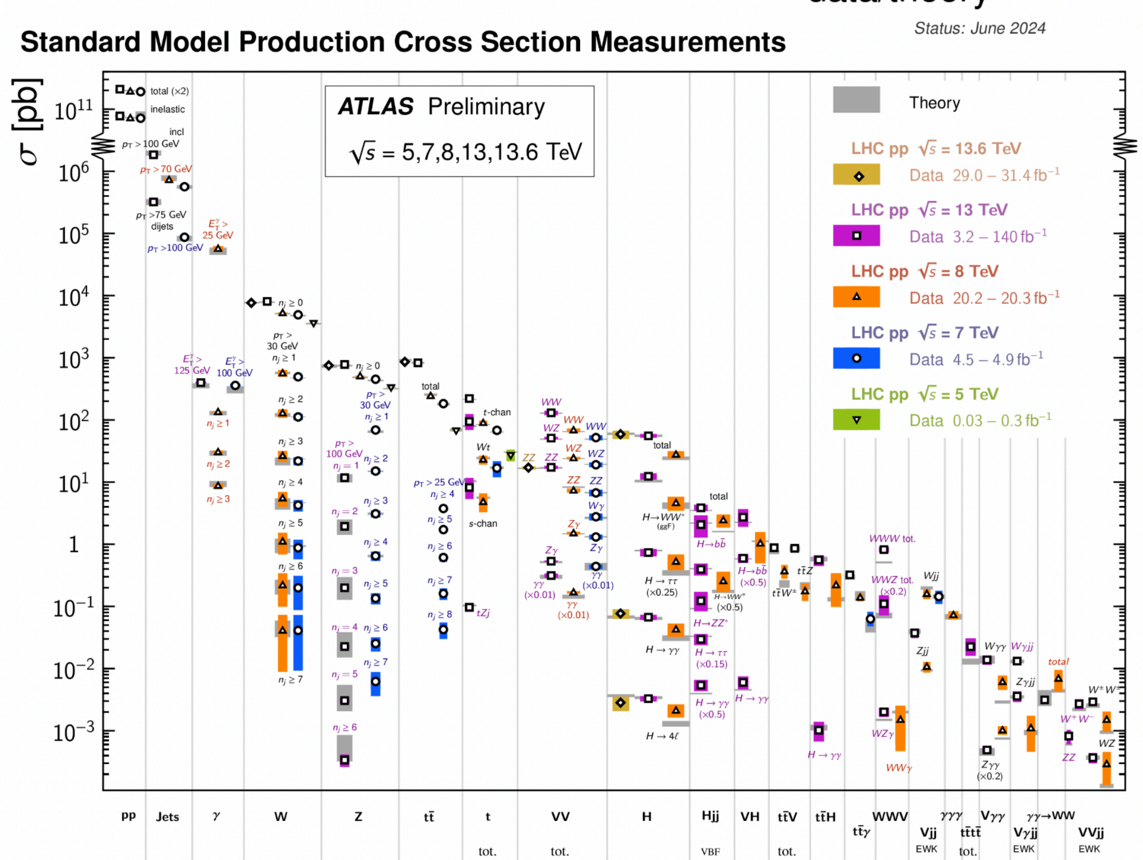
2024.10.16

Based on: *JHEP* 04 (2024) 081 and 2408.13304

with: Hsin-Chia Cheng (Davis), Lingfeng Li (Brown), and Ennio Salvioni (Sussex)

The SM & its Extension





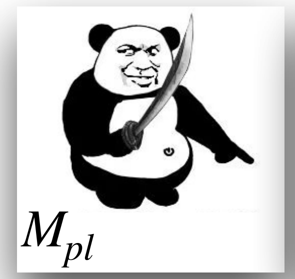
The SM:

- Well measured
- Consistent with data mostly

[ATL-PHYS-PUB-2024-011]

Elegant, but with problems:

- Unnatural



Hierarchy!

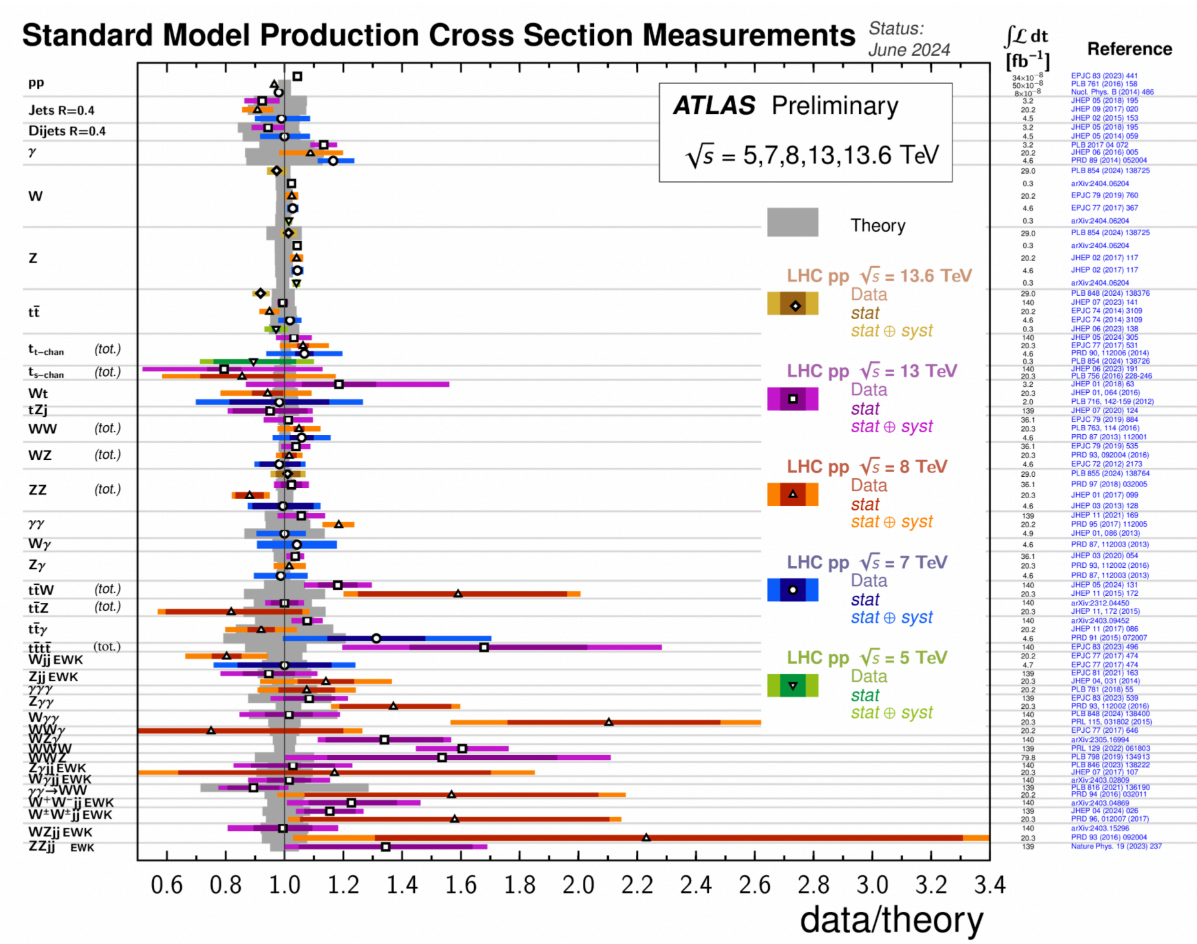
$$M_{pl} \gg M_H$$

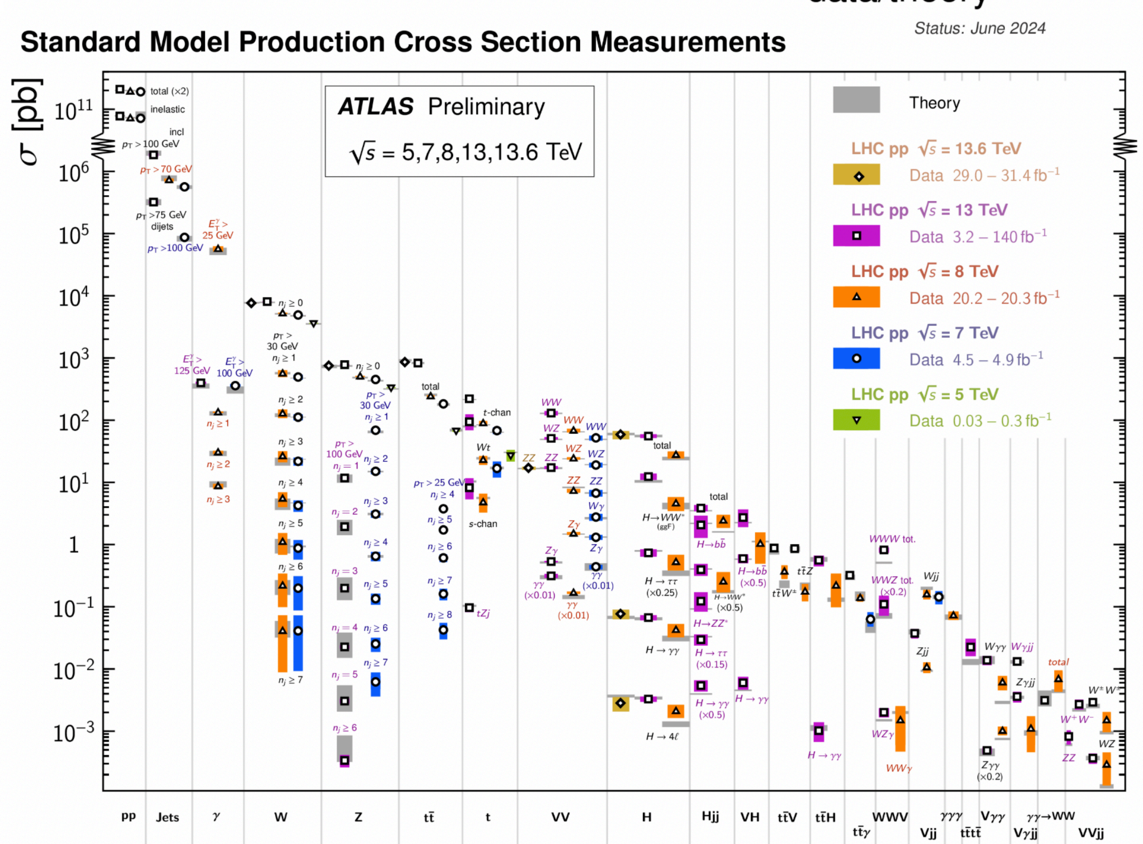
To destabilise the vacuum.

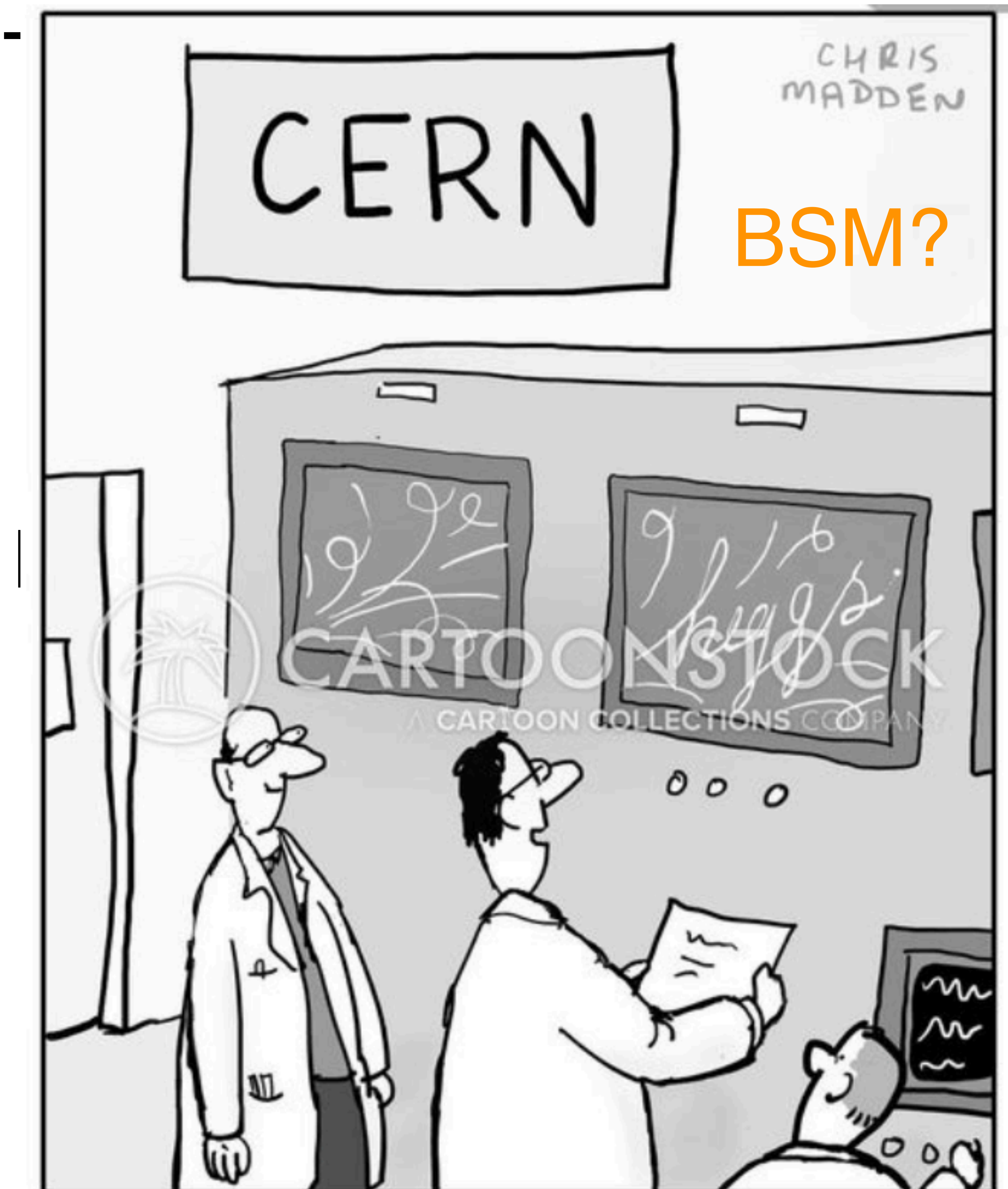
- Absence of darkness

Universe: mostly dark

The SM & its Extension





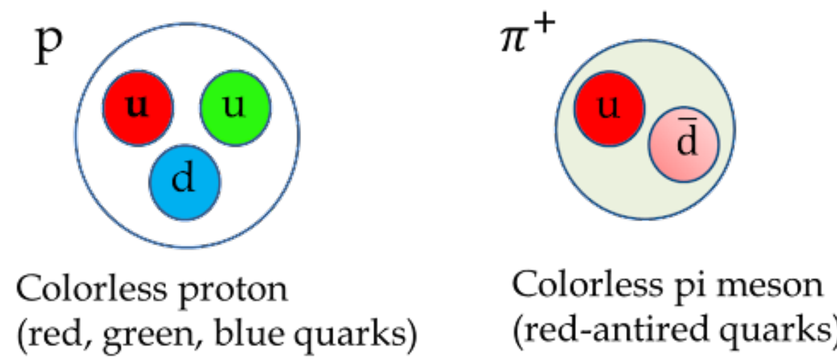


"Take a look at this everyone - it just could be the signature we've been looking for!"

Dark QCD

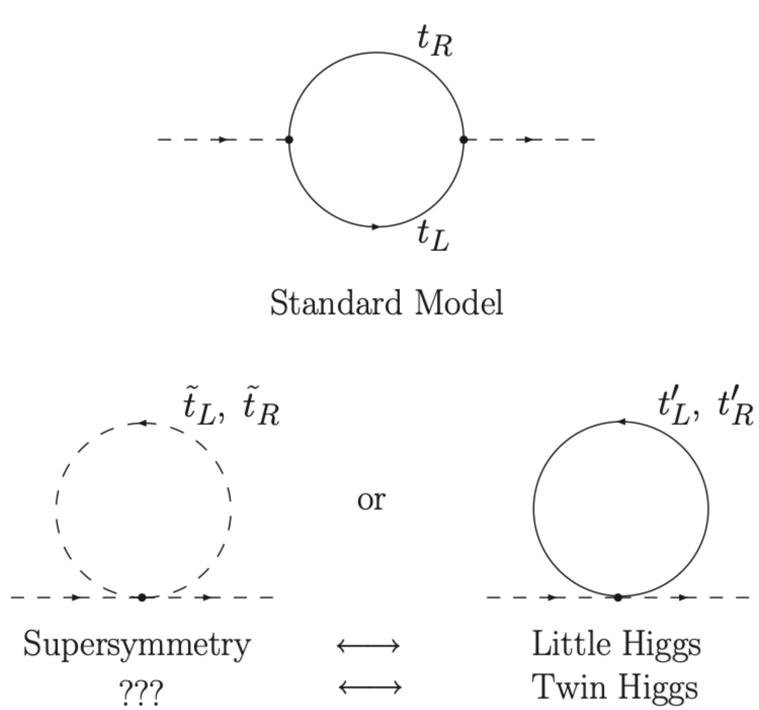
QCD: profound,

but with hints for BSM



- neutral naturalness

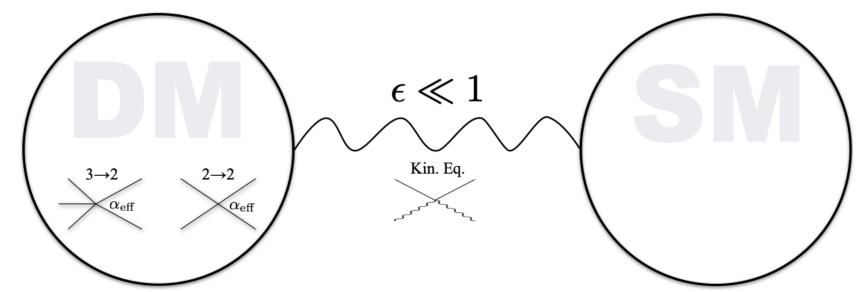
  [Chacko. et al.] [Burdman. et al.]



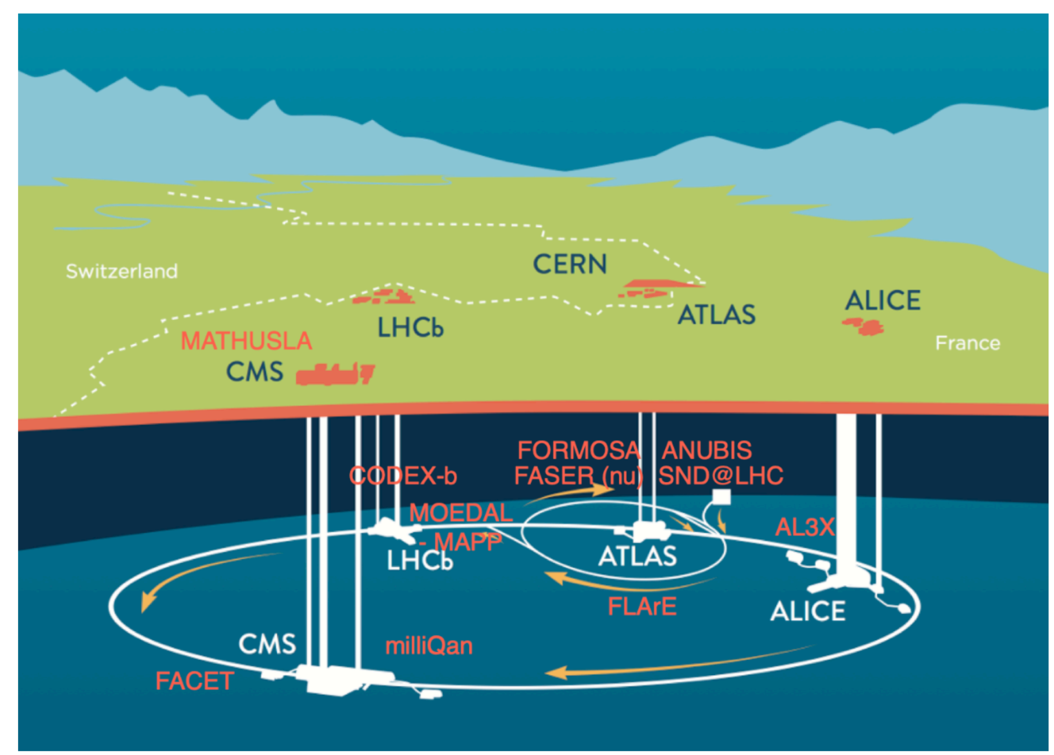
- LLP detections

- dark matter candidates

  [Y. Hochberg. et al.]

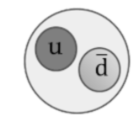


SIMP? $3 \to 2$



Dark Hadrons

The lightest as dark pions:



Colorless pi meson
(red-antired quarks)

$\hat{\pi}$ *to consider CP!*

- CP-odd $\hat{\pi}_1$ and $\hat{\pi}_3$

From Z-portal

As axion-like particles

$$\mathscr{L} = -\, C_f \frac{\partial_\mu \hat{\pi}_b}{f_a^{(b)}} \bar{f}\gamma^\mu \gamma^5 f$$

- CP-even $\hat{\pi}_2$

From Higgs-portal

To introduce a scalar mixing with the h

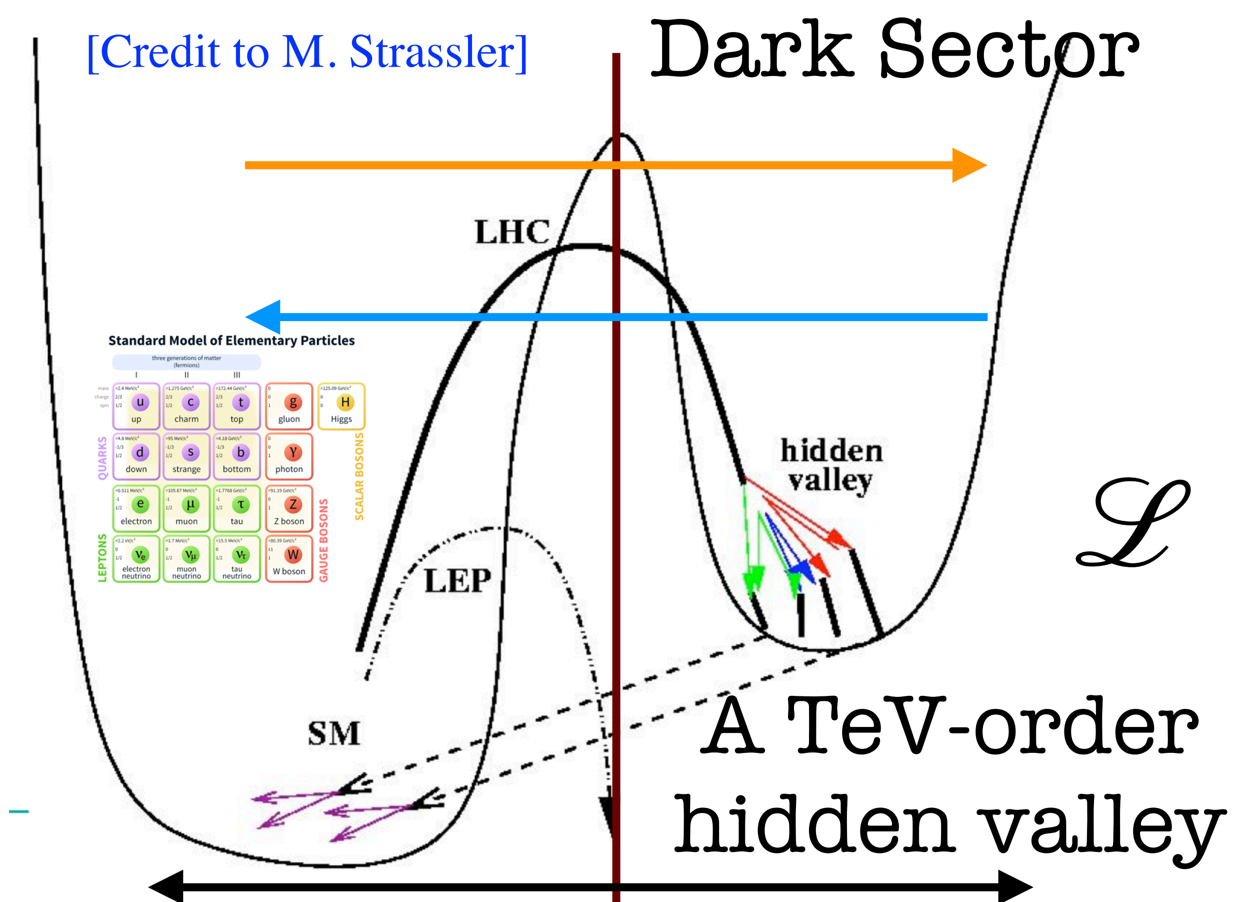
$$\mathscr{L} = -\boxed{\sin\theta_s}\frac{m_f}{v}\phi\bar{f}f$$

$$\begin{pmatrix} h \\ \phi \end{pmatrix} = \begin{pmatrix} \cos\theta_s & \sin\theta_s \\ -\sin\theta_s & \cos\theta_s \end{pmatrix} \begin{pmatrix} \hat{h} \\ \hat{\phi} \end{pmatrix}$$

A tiny mixing

The Hidden Valley

[Credit to M. Strassler]



EW Scale
vev: 246 GeV

EW forces (Z/h…)
to connect the two

- Z/h exotic decays
- Back into SM particles to be detected

Induced from EFT:

$$\mathscr{L} \sim \frac{c}{2M^2}\left(iH^\dagger \overleftrightarrow{D}_\mu H\right)\left(\bar{\psi}\, \gamma^\mu\, \psi\right)$$

SM singlet

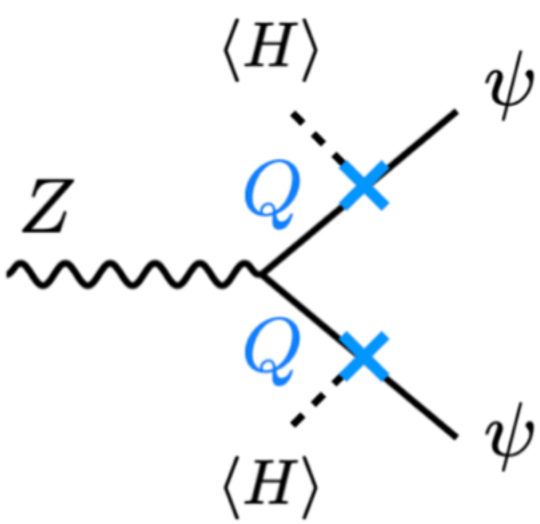
- to enable Z/h coupling with the dark
- to consider dark pions and showering

The EW Portal

$$\mathcal{L} \sim \frac{c}{2M^2}\left(iH^\dagger \overleftrightarrow{D}_\mu H\right)\left(\bar{\psi}\,\gamma^\mu\,\psi\right)$$

Two types of UV completions:

- Fermionic

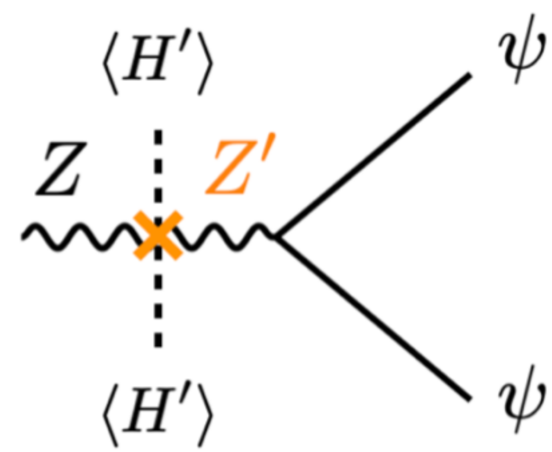


$$\mathcal{L} \sim \bar{Q} Y \psi H$$

$$\frac{c}{M^2} \sim \frac{Y^2}{M_Q^2}$$

To introduce a heavy fermion doublet

- Gauge



$$\mathcal{L} \sim \delta \hat{M}^2 Z^\mu Z'_\mu$$

$$\frac{c}{M^2} \sim \frac{g_D^2 \delta \hat{M}^2}{M_Z^2 M_{Z'}^2}$$

Mass mixing: Z' either heavier or lighter than Z

[Cheng et al.]

The EW Portal & its UV

- Fermionic

A light singlet

A heavy doublet

$$-\mathcal{L}_{\rm UV} = \overline{Q}_L \boldsymbol{Y} \psi_R H + \overline{Q}_R \widetilde{\boldsymbol{Y}} \psi_L H + \overline{Q}_L \boldsymbol{M} Q_R + \overline{\psi}_L \boldsymbol{\omega} \psi_R + \text{h.c.}$$

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

- Gauge

$$\mathcal{L}_{\rm mix} = -\frac{\sin\chi}{2} \hat{Z}'_{\mu\nu} \hat{B}^{\mu\nu} + \delta \hat{M}^2 \hat{Z}'^{\mu} \hat{Z}_\mu$$

Kinetic and mass mixing

$$\text{BR}(Z \to \psi' \overline{\psi}') \approx 1.4 \times 10^{-4} \left(\frac{N_d}{3} \right) \left(\frac{\xi}{0.01} \right)^2 g_D^2 \sum_i (x_{Li}^2 + x_{Ri}^2)$$

With

$$\tan 2\xi = \frac{-2\cos\chi(\delta\hat{M}^2 + \hat{M}_Z^2 \hat{s}_W \sin\chi)}{\hat{M}_{Z'}^2 - \hat{M}_Z^2 \cos^2\chi + \hat{M}_Z^2 \hat{s}_W^2 \sin^2\chi + 2\delta\hat{M}^2 \hat{s}_W \sin\chi}$$

Flavors

Down-type FCNC:

$$\sim [\bar{d}_i \gamma^\mu d_j] \cdot [\bar{\psi} \gamma_\mu \psi]$$

$$\mathcal{L}_{\rm eff}^{\rm FCNC} = -\, g_D \hat{g}_Z \frac{\delta \hat{M}^2}{M_Z^2 M_{Z'}^2 \cos^2\chi} \frac{g^2}{128\pi^2} J_D^\mu \bar{d}_j \gamma_\mu P_L d_i \sum_{q\,\in\, u,c,t} V_{qj}^* V_{qi} \mathcal{K}_q + \text{h.c.}$$

[He, Tandean and Valencia]

where

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

Decays of b-hadrons/Kaons:

$$\text{BR}(B^{+,0} \to \{K^+ \hat{\pi}_b, K^{*0} \hat{\pi}_b\}) \approx \{0.92, 1.1\} \times 10^{-8} \left(\frac{1\ \text{PeV}}{f_a^{(b)}}\right)^2 \left(\frac{\mathcal{K}_t}{10}\right)^2 \{\lambda_{BK\hat{\pi}}^{1/2}, \lambda_{BK^*\hat{\pi}}^{3/2}\}$$

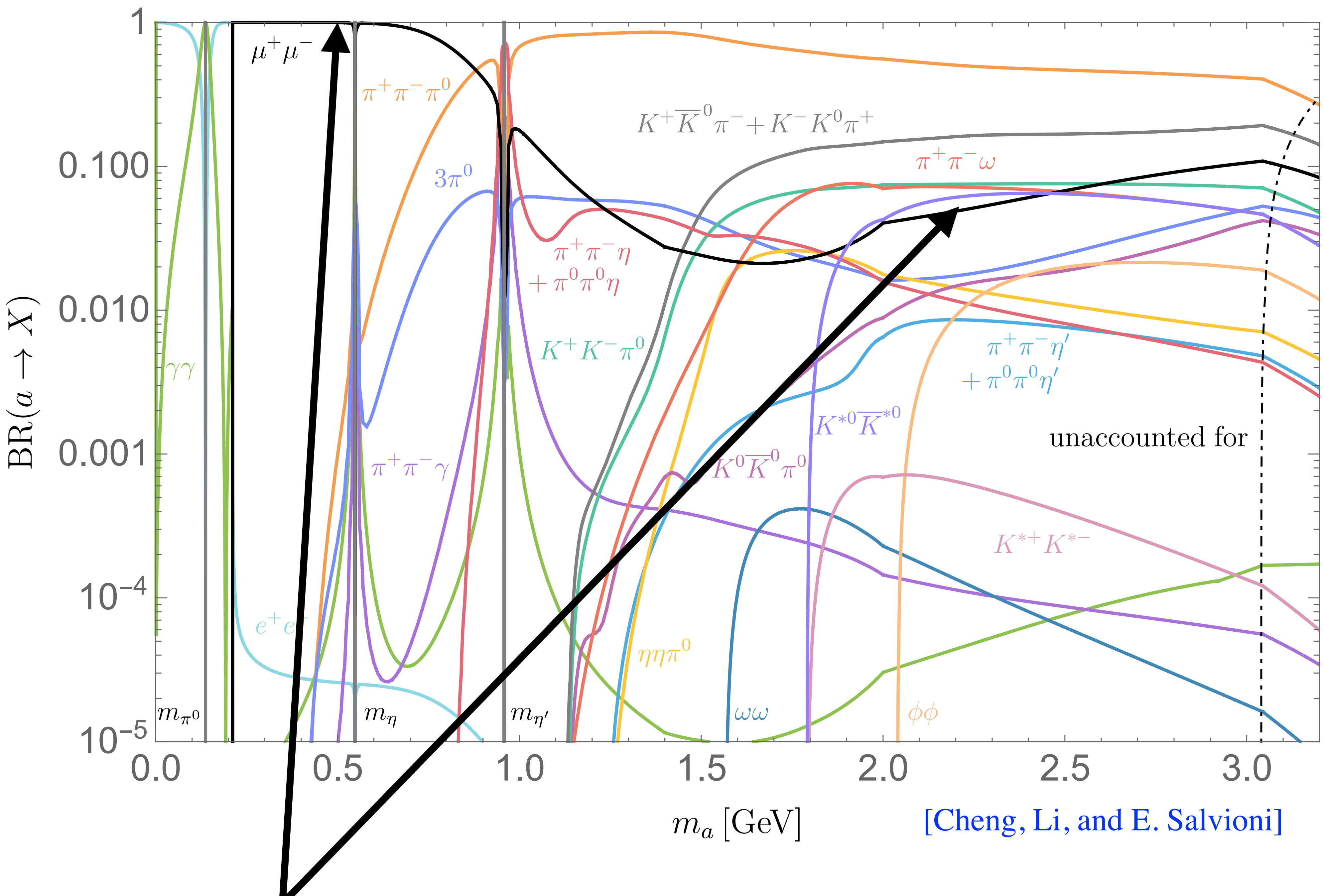
dark pions to be light LLPs!

Flavor portal opens!

Dark Pions

CP-odd dark pions as ALPs

$$\mathscr{L} = -C_f \frac{\partial_\mu \hat{\pi}_b}{f_a^{(b)}} \bar{f}\gamma^\mu\gamma^5 f$$



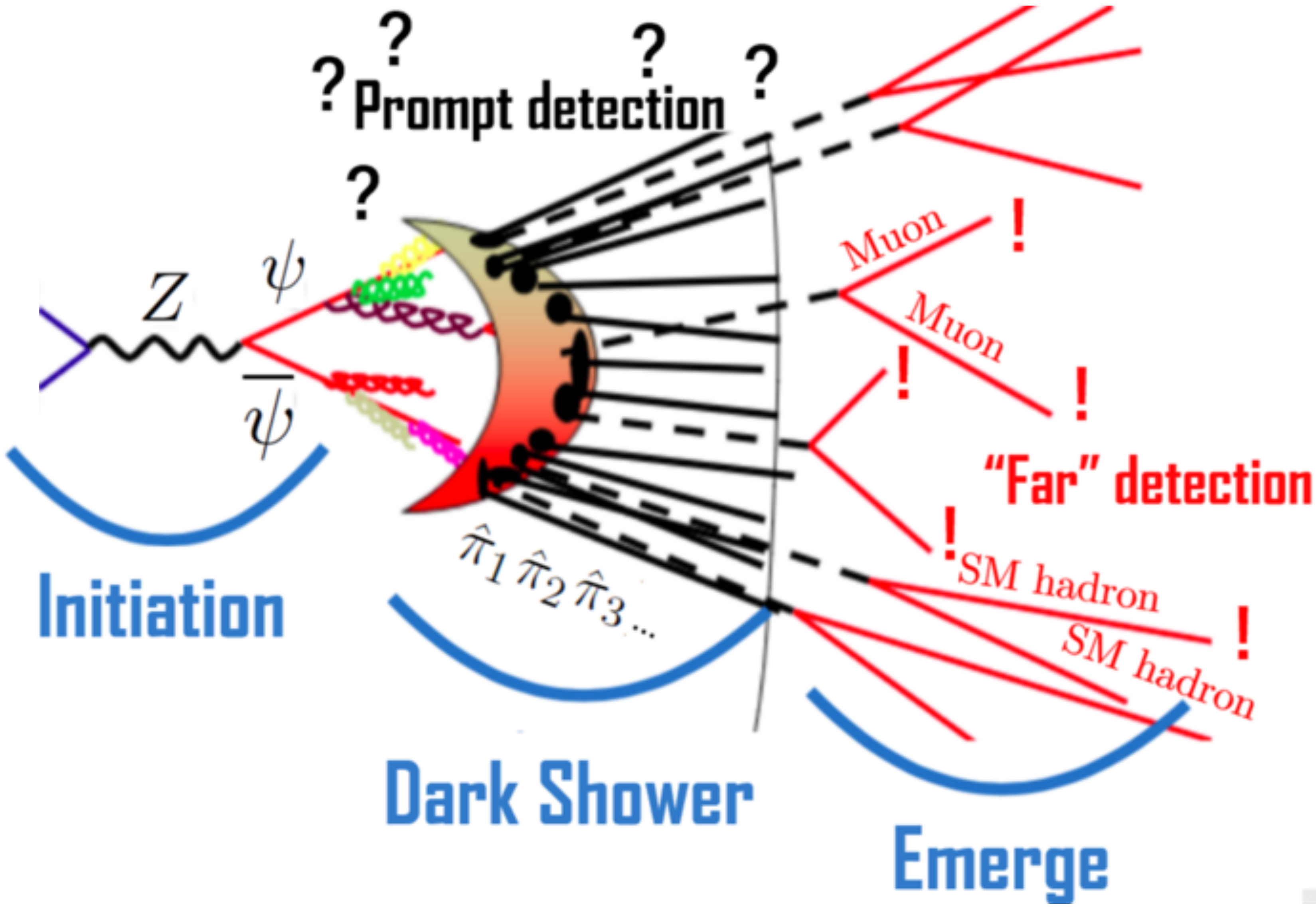
[Cheng, Li, and E. Salvioni]

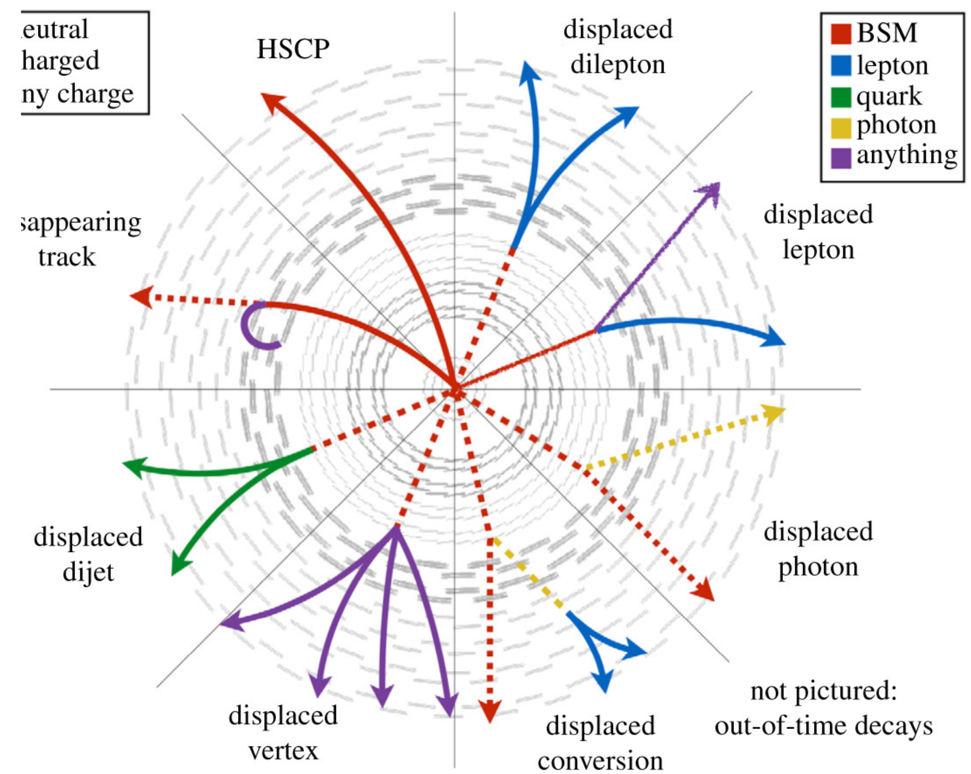
$\hat{\pi} \to \mu^+\mu^-$

Di-muon dominates at light masses;
Still relevant for heavy cases

Dark Showers

Illustrations of dark showers





[Credit to J. Antonelli]

- Detector setup: far or prompt;
  To be sensitive to different lifetime ranges
- Balance between "farther, SM bkg harder to reach" & (closer, a wider solid angle)

Opportunities@FCC

- Z factory: up to $\mathcal{O}(10^{12})$ Z bosons

With a clean environment,
advanced technologies, etc.

$Z \to$ DS: to be promising

- Also as a flavor machine

	Belle II	LHCb	Tera-Z	10×Tera-Z
B^0, $\bar{B}^0$	5.3×10^{10}	6×10^{13}	1.2×10^{11}	1.2×10^{12}
$B^\pm$	5.6×10^{10}	6×10^{13}	1.2×10^{11}	1.2×10^{12}
B_s, $\bar{B}_s$	5.7×10^{8}	2×10^{13}	3.1×10^{10}	3.1×10^{11}
$B_c^\pm$	-	4×10^{11}	1.8×10^{8}	1.8×10^{9}
Λ_b, $\bar{\Lambda}_b$	-	2×10^{13}	2.5×10^{10}	2.5×10^{11}

[Ho, **Jiang**, Kwok, Li and Liu]

Abundant b-hadrons produced

FCNC: of complementarities

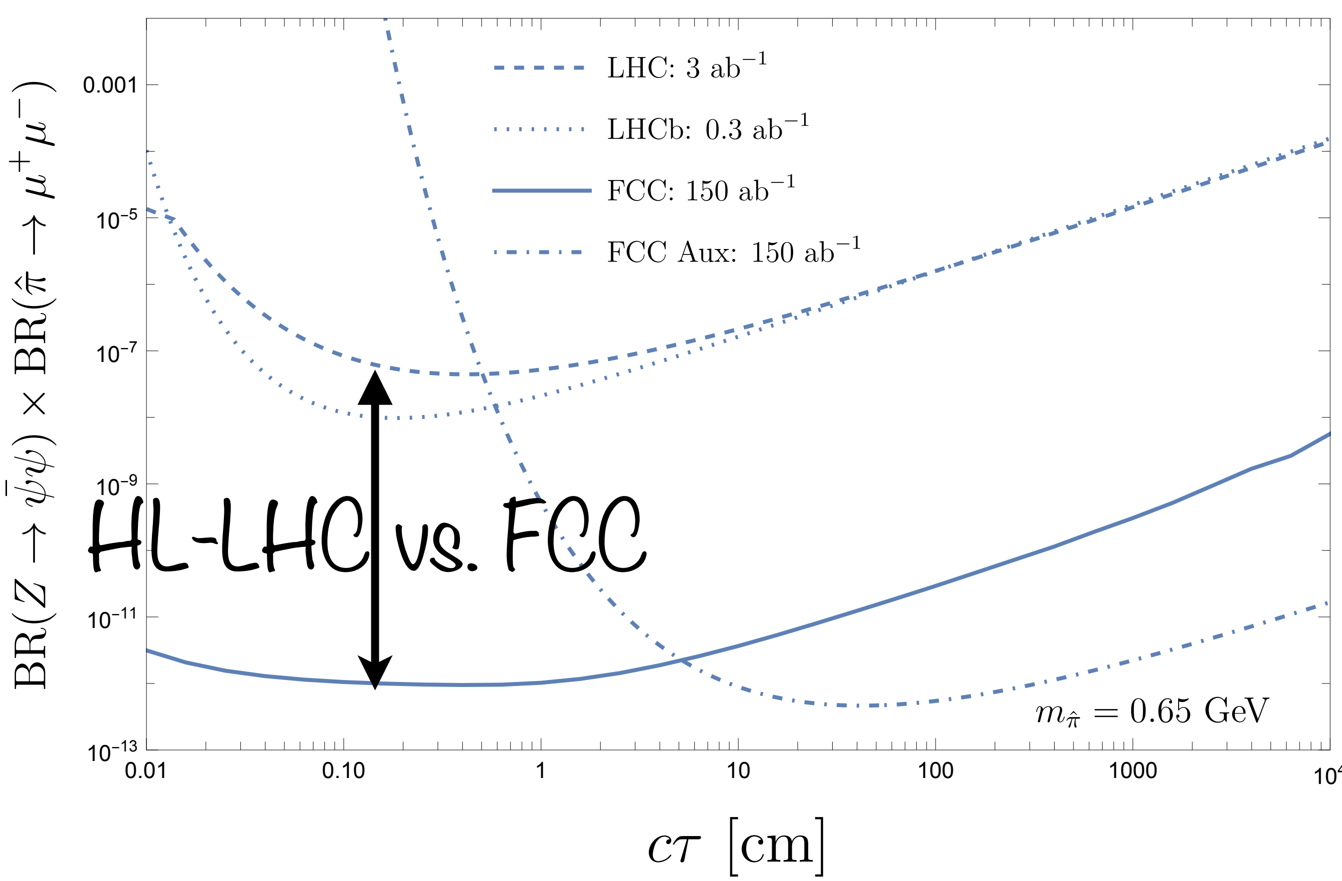
Opportunities@FCC

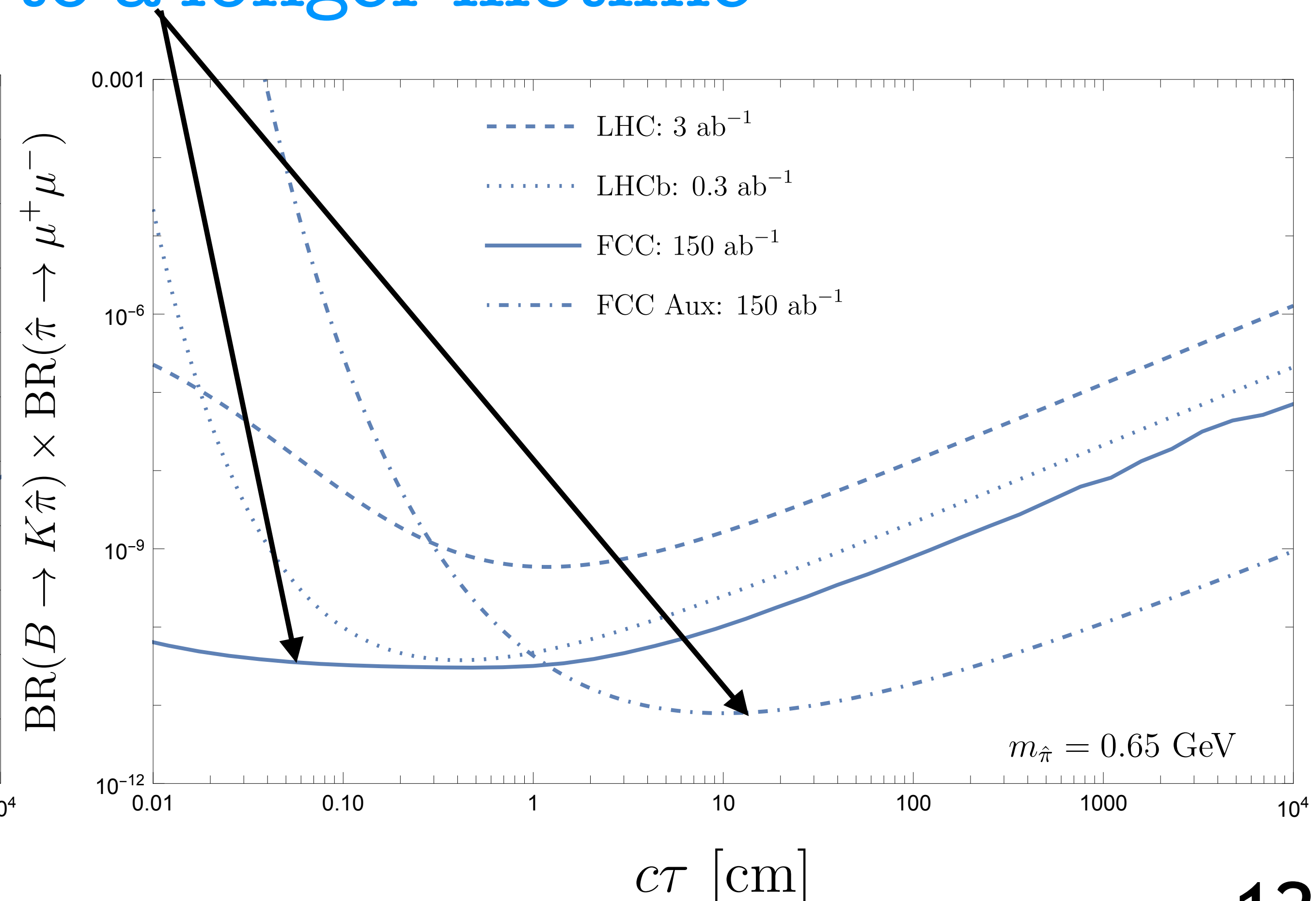
- DS and FCNC: dimuon search, with: $p_t^{\mu\mu} > 2$ GeV, $|\eta^{\mu\mu}| < 5$

  $|p|^{\mu_i} > 10$ GeV, $p_t^{\mu_i} > 0.5$ GeV, $|\eta^{\mu_i}| < 5$ $(i = 1, 2)$

  $0.5 < l_{xy} < 100$ cm
- Stronger, compared to CMS scouting and LHCb
- Auxiliary detectors, like HECATE, with: $\ell_{xy} < 15$ m, $0 < \ell_z < 25$ m, $4 < \ell < 25$ m

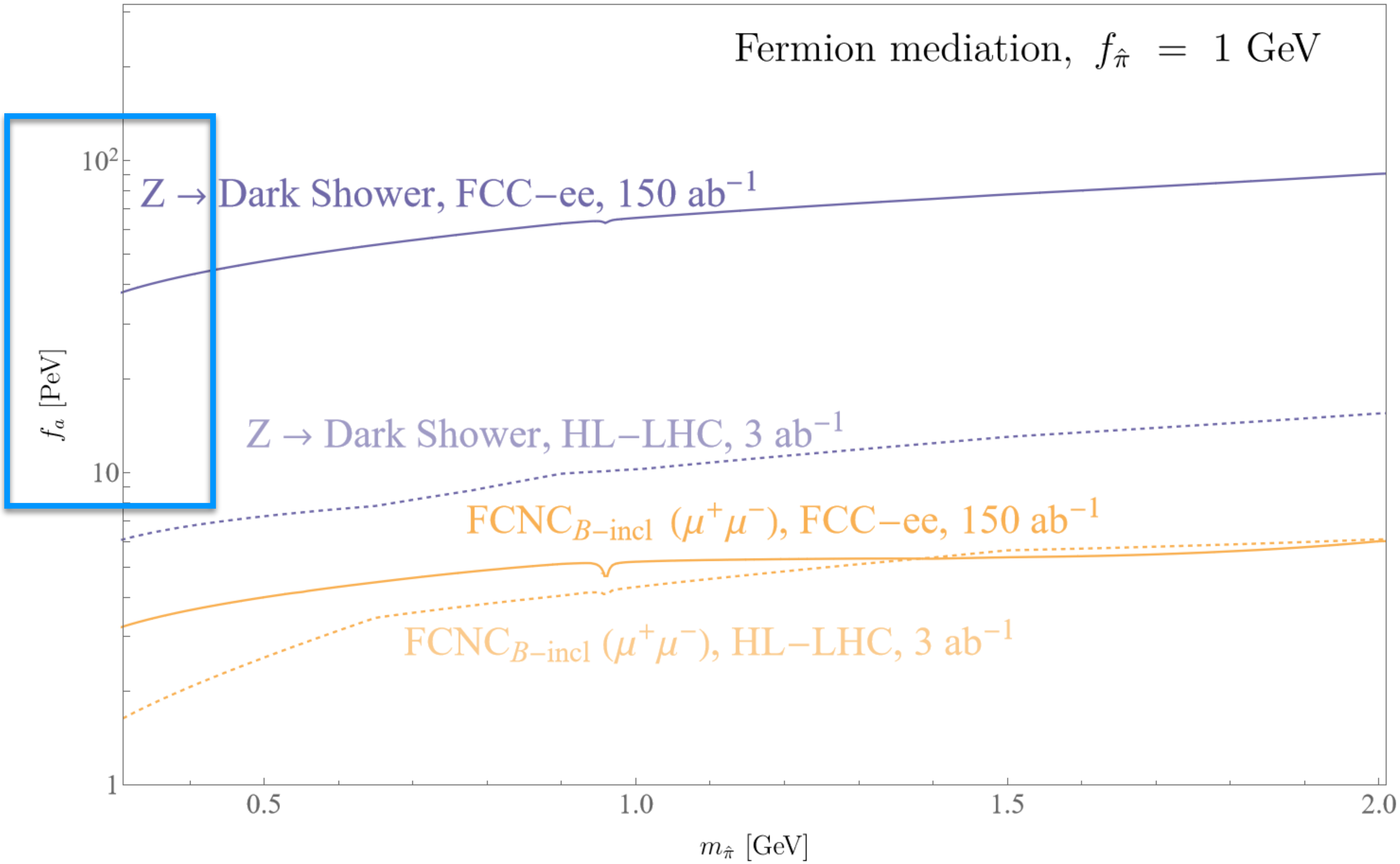
Farther; Sensitive to a longer lifetime





Opportunities@FCC

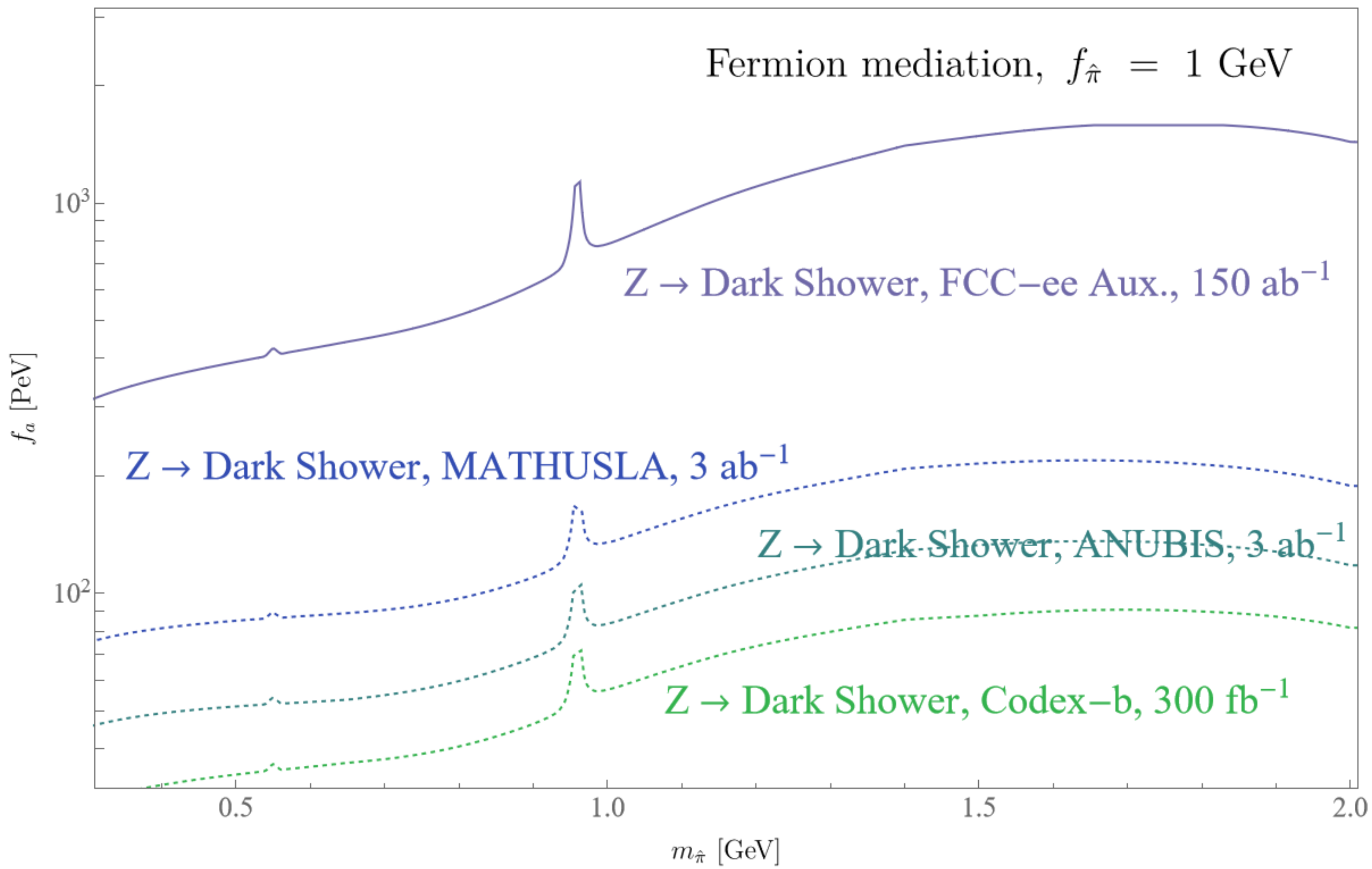
Model-dependent constraints: (prompt)



Pushed up to $\mathcal{O}(10)$ PeV!

Opportunities@FCC

Model-dependent constraints: (far)



DS: to be competitive, compared with auxiliary detectors at the LHC

Summary & Outlook

- EW portal to BSM: to be promising
- Rich phenomenology
- What about heavier dark mesons?
  Or even dark baryons?
  What about dark FCNC signals?
- As dark matter candidates. Cosmology?!

Back-Up

The full Lagrangian

$$\mathcal{L}_{\rm SM} = -\frac{1}{4}\hat{B}_{\mu\nu}\hat{B}^{\mu\nu} - \frac{1}{4}\hat{W}^3_{\mu\nu}\hat{W}^{3\mu\nu} + \frac{1}{2}\hat{M}_Z^2\hat{Z}_\mu\hat{Z}^\mu - \hat{e}\sum_f \bar{f}\gamma^\mu\left(\frac{Y_f}{\hat{c}_W}\hat{B}_\mu + \frac{T^3_{Lf}}{\hat{s}_W}\hat{W}^3_\mu\right)f, \quad (2.2)$$

$$\mathcal{L}_{\rm dark} = -\frac{1}{4}\hat{Z}'_{\mu\nu}\hat{Z}'^{\mu\nu} + \frac{1}{2}\hat{M}^2_{Z'}\hat{Z}'_\mu\hat{Z}'^\mu - g_D\sum_{j=1}^{N}\left(\overline{\psi}_j\gamma^\mu x_L^j P_L\psi_j + \overline{\psi}_j\gamma^\mu x_R^j P_R\psi_j\right)\hat{Z}'_\mu \quad (2.3)$$

$$-\frac{1}{4}G^D_{a\,\mu\nu}G^{D\,\mu\nu}_a + \sum_{j=1}^{N} i\overline{\psi}_j \not{D}_G\psi_j - \sum_{i,j=1}^{N}\left(\overline{\psi}_{Li}m_{ij}\psi_{Rj} + \overline{\psi}_{Li}\zeta^1_{ij}\psi_{Rj}\Phi + \overline{\psi}_{Ri}\zeta^2_{ij}\psi_{Lj}\Phi + \text{h.c.}\right),$$

$$\mathcal{L}_{\rm mix} = -\frac{\sin\chi}{2}\hat{Z}'_{\mu\nu}\hat{B}^{\mu\nu} + \delta\hat{M}^2\hat{Z}'^\mu\hat{Z}_\mu - \kappa\,\Phi^*\Phi H^\dagger H\,, \quad (2.4)$$

Pions:

$$< 0\,|\,j^\mu_{5a}(0)\,|\,\hat{\pi}_b(p) > = -\,i\delta_{ab}f_{\hat{\pi}}p^\mu$$

$$j^\mu_{5a} = \bar{\psi}\gamma^\mu\gamma_5\frac{\sigma_a}{2}\psi$$

Mixing and Interactions

Mass eigenstates via transformations:

$$\begin{pmatrix} A_\mu \\ Z_\mu \\ Z'_\mu \end{pmatrix} = L^{-1} \begin{pmatrix} \hat{A}_\mu \\ \hat{Z}_\mu \\ \hat{Z}'_\mu \end{pmatrix}$$

with

$$L = \begin{pmatrix} 1 & -\hat{c}_W \sin\xi \tan\chi & -\hat{c}_W \cos\xi \tan\chi \\ 0 & \cos\xi + \hat{s}_W \sin\xi \tan\chi & -\sin\xi + \hat{s}_W \cos\xi \tan\chi \\ 0 & \sin\xi / \cos\chi & \cos\xi / \cos\chi \end{pmatrix}$$

$$\tan 2\xi = \frac{-2\cos\chi(\delta \hat{M}^2 + \hat{M}_Z^2 \hat{s}_W \sin\chi)}{\hat{M}_{Z'}^2 - \hat{M}_Z^2 \cos^2\chi + \hat{M}_Z^2 \hat{s}_W^2 \sin^2\chi + 2\delta\hat{M}^2 \hat{s}_W \sin\chi}$$

Dark Z’

Physical Z

$$-\begin{pmatrix} \hat{e}J^\mu_{\mathrm{EM}} & \hat{g}_Z \hat{J}^\mu_Z & g_D J^\mu_D \end{pmatrix} \begin{pmatrix} \hat{A}_\mu \\ \hat{Z}_\mu \\ \hat{Z}'_\mu \end{pmatrix} = -\begin{pmatrix} \hat{e}J^\mu_{\mathrm{EM}} & \hat{g}_Z \hat{J}^\mu_Z & g_D J^\mu_D \end{pmatrix} L \begin{pmatrix} A_\mu \\ Z_\mu \\ Z'_\mu \end{pmatrix}$$

The EW Precision Test

Electroweak parameters, definitions:

$$\mathcal{L}_{Zf\bar{f}} = -\frac{\bar{Z}e}{s_W c_W}\bar{f}\gamma^\mu(T^3_{Lf} - s_*^2 Q_f)fZ_\mu \,,$$

[M. Peskin and T. Takeuchi]

[M. Peskin and T. Takeuchi]

$$\bar{Z} = 1 + \frac{\alpha T}{2}\,, \qquad s_*^2 = s_W^2 + \frac{\alpha}{c_W^2 - s_W^2}\left(\frac{S}{4} - s_W^2 c_W^2 T\right),$$

$$\frac{M_W^2}{M_Z^2} = c_W^2 + \frac{\alpha c_W^2}{c_W^2 - s_W^2}\left(-\frac{S}{2} + c_W^2 T + \frac{c_W^2 - s_W^2}{4 s_W^2} U\right).$$

$$S = \frac{4 s_W^2}{\alpha}\left(\frac{c_W^2}{s_W}\xi t_\chi - c_W^2 \xi^2\right), \quad T = \frac{1}{\alpha}\left(2 s_W \xi t_\chi + \xi^2\left(\frac{M_{Z'}^2}{M_Z^2} - 2\right)\right), \quad U = \frac{4 s_W^2}{\alpha} c_W^2 \xi^2 \,,$$

Constraints using the PDG fit

[B. Holdom]

$$\tan 2\xi = \frac{-2\cos\chi(\delta\hat{M}^2 + \hat{M}_Z^2 \hat{s}_W \sin\chi)}{\hat{M}_{Z'}^2 - \hat{M}_Z^2\cos^2\chi + \hat{M}_Z^2 \hat{s}_W^2 \sin^2\chi + 2\delta\hat{M}^2 \hat{s}_W \sin\chi}$$

A flat direction: $\xi = 0$

i.e. $\sin\chi = -\,\hat{s}_W\ \delta\hat{M}^2/\hat{M}_Z^2$

Constraints From the Low-Energy

Low energy parameters: $E \ll M_{Z'} < M_Z$

$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\rho_*(0)\left[J_3^\mu J_{3\,\mu} - 2s_*^2(0)J_3^\mu J_{\rm EM\,\mu} + O(J_{\rm EM}^2)\right]$$

$$\rho_*(0) = 1 + \alpha T + \frac{M_Z^2}{M_{Z'}^2}(\xi - s_W \tan\chi)^2 ,$$

$$\frac{s_*^2(0)}{s_W^2} = \frac{s_*^2}{s_W^2} + \frac{M_Z^2}{M_{Z'}^2}\left(c_W^2 \tan^2\chi - \frac{c_W^2}{s_W}\xi \tan\chi\right) ,$$

- Atomic Parity Violation (APV)

  Weak charge of the Caesium atom:

  [G. Altarelli et. Al.] $Q_W \approx Q_W^{\rm SM}\left(1 + \delta\rho_*(0) + 2.91\,\delta s_*^2(0)\right)$

- Parity Violation: $e^- e^- \to e^- e^-$ at E158 at SLAC.

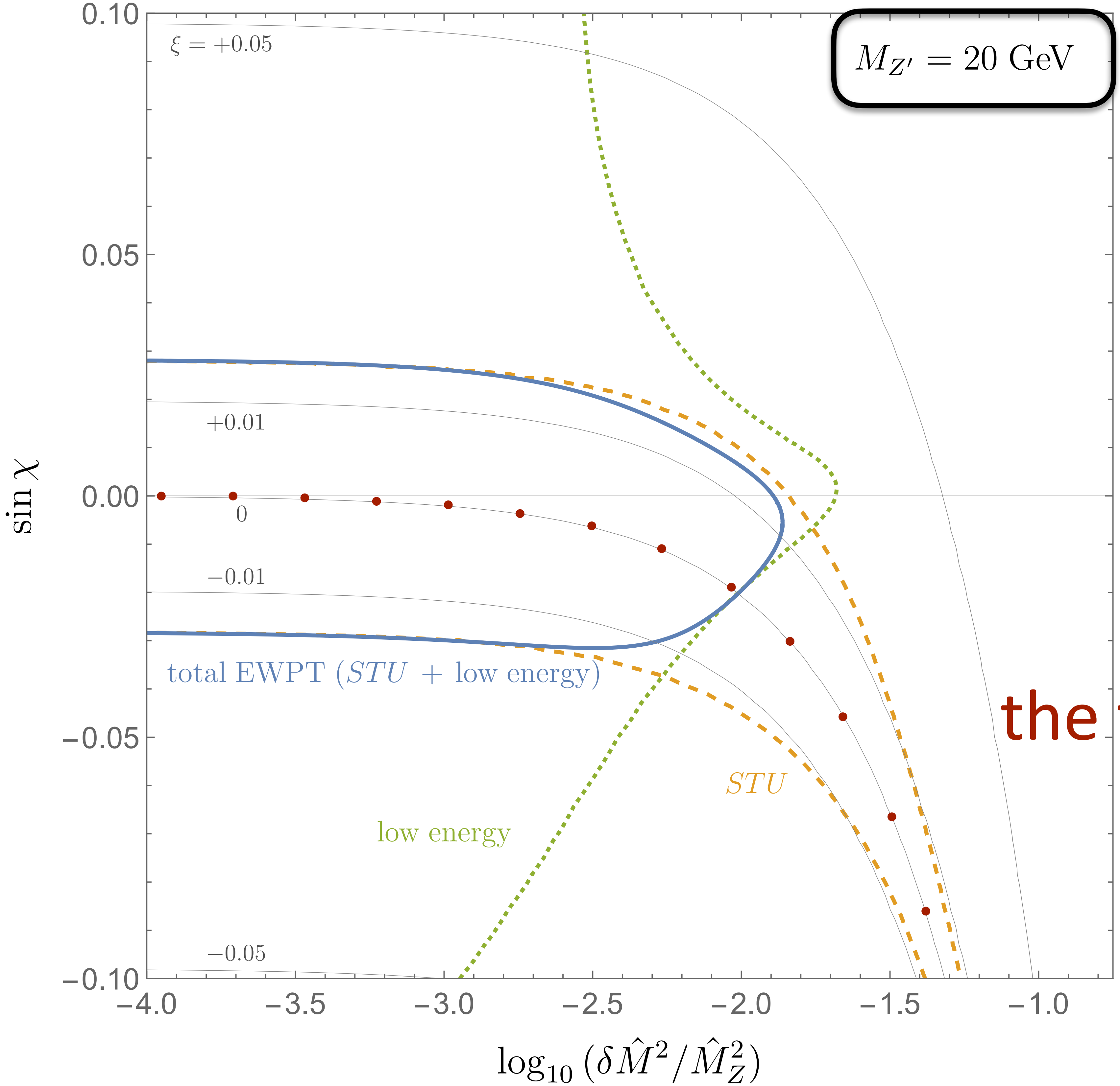
  [K. S. Kumar]

  Effective coupling: $g_{AV}^{ee} \approx g_{AV}^{ee,\,\rm SM}\left(1 + \delta\rho_*(0) - 87.0\,\delta s_*^2(0)\right)$

- Weak charge of proton: $e^- p \to e^- p$ [QWEAK Collaboration]

  Effective coupling: $g_{AV}^{ep} \approx g_{AV}^{ep,\,\rm SM}\left(1 + \delta\rho_*(0) - 87.0\,\delta s_*^2(0)\right)$

Complementarity



- Heavier:
  to be integrated out as EFT
- Lighter:
  bounds from B-factory

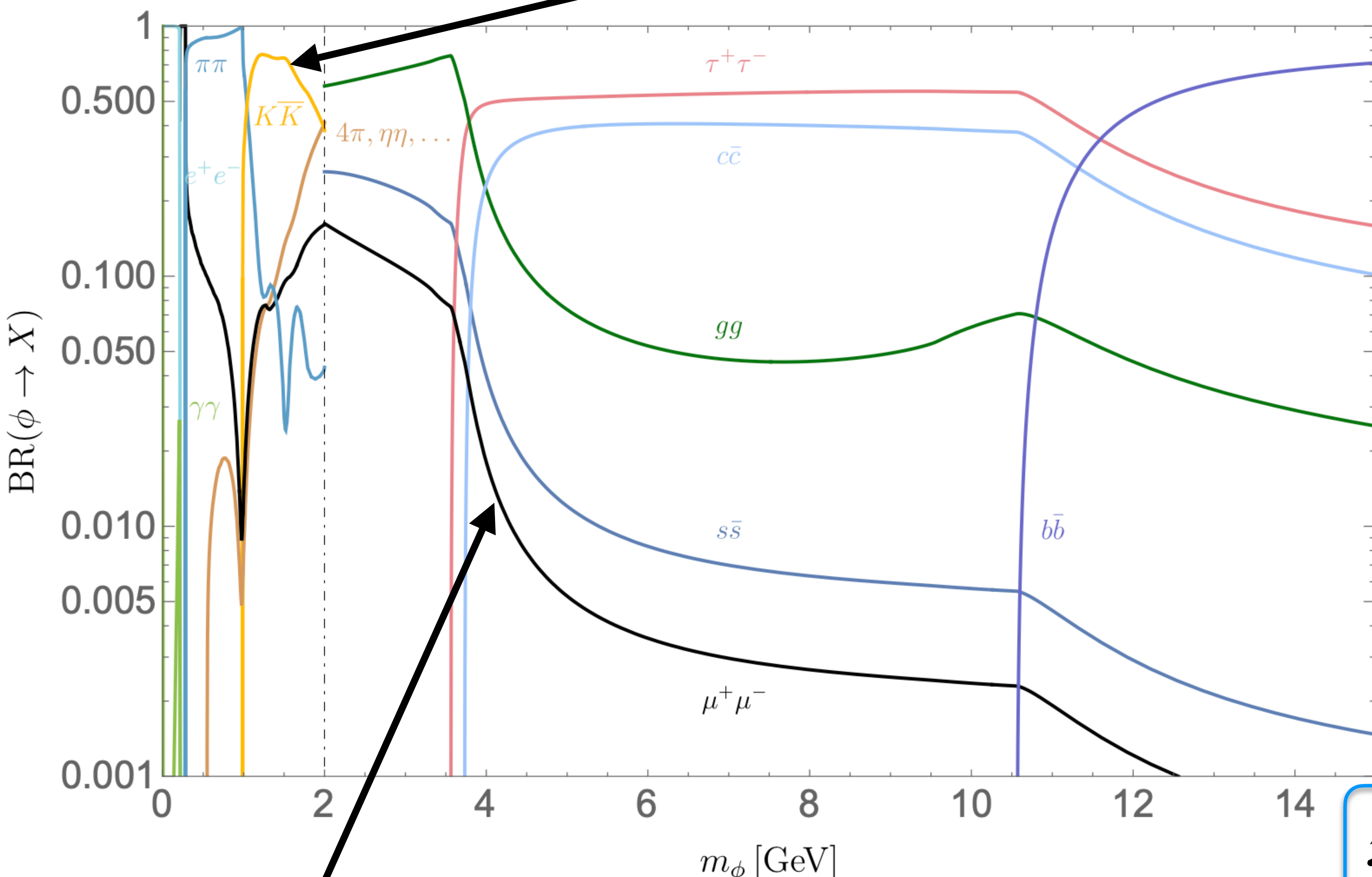
Complementarity:
the flat direction removed

$$\sin\chi = -\,\hat{s}_W\,\delta\hat{M}^2/\hat{M}_Z^2$$

Dark Pions

CP-even pions

di-kaon important for light pions



di-muon always relevant

$\hat{\pi} \to \mu^+\mu^-$

$\hat{\pi} \to K^+K^-$

CMS & HL-LHC

Dimuon trigger stream (scouting)

- Transverse displacement

  Current: $\ell_{xy} < 11$ *cm*

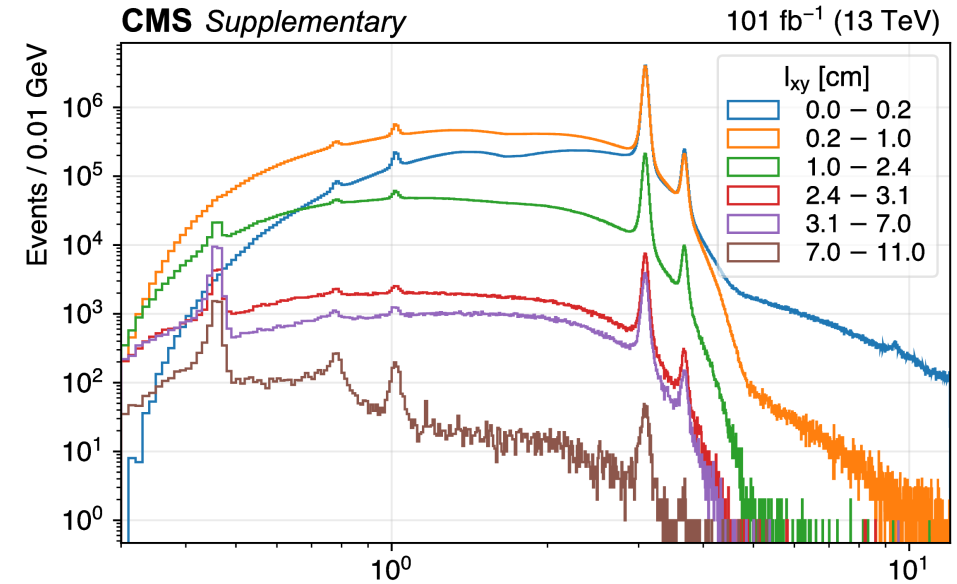
  10 times longer for HL-phase

- Luminosity

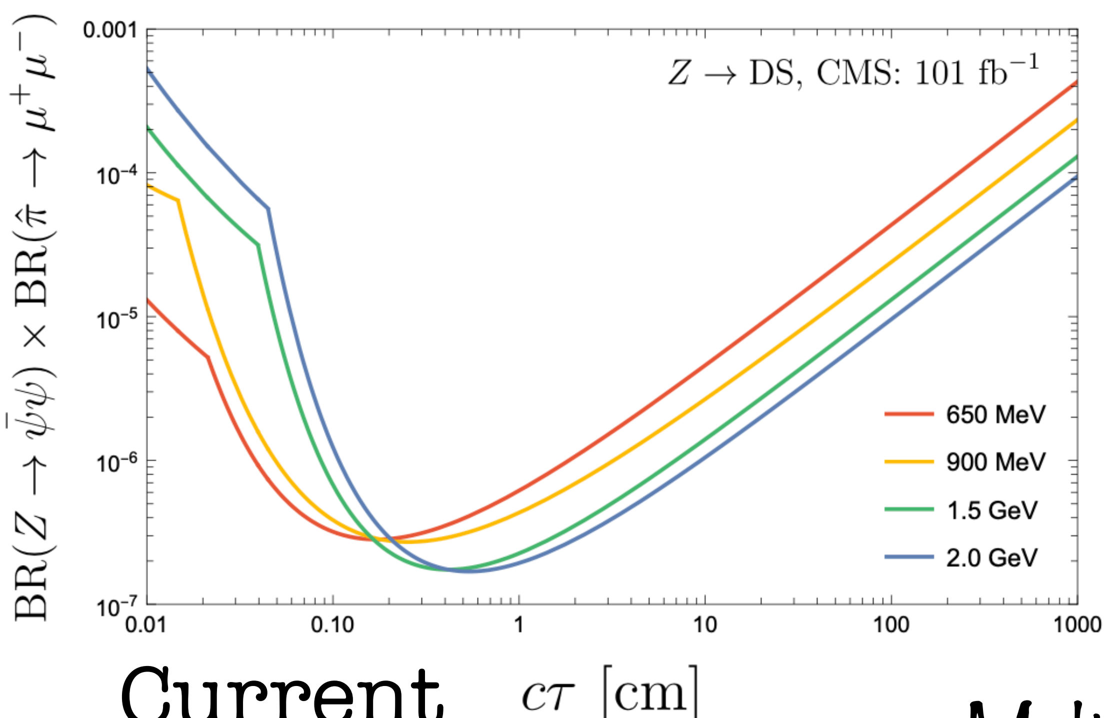
  30 times larger for HL-phase

- Detector/Algorithm

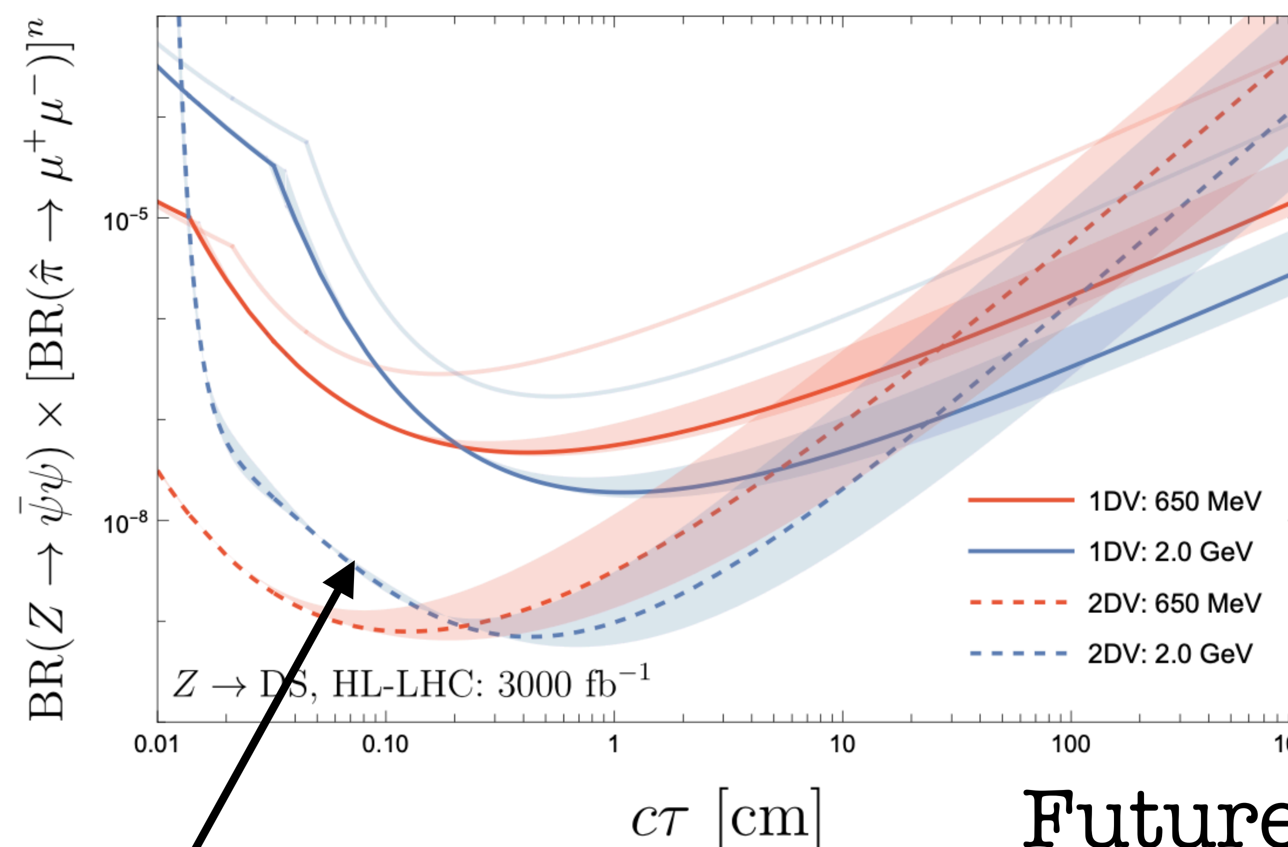
  To be updated as well



[CMS Collaboration]



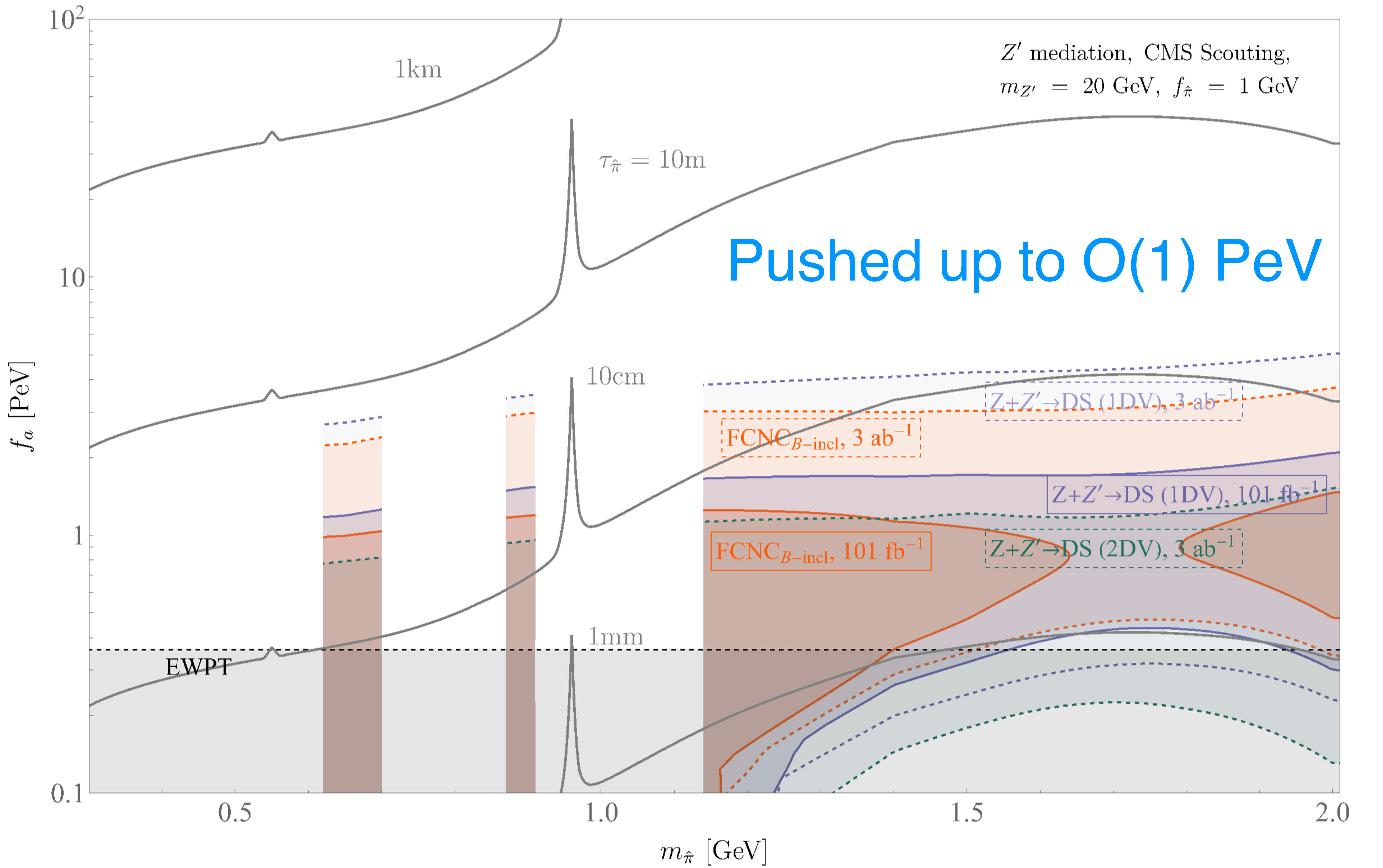
Current



Future

Multi-DV(assuming bkg-free) becomes possible!

CMS & HL-LHC



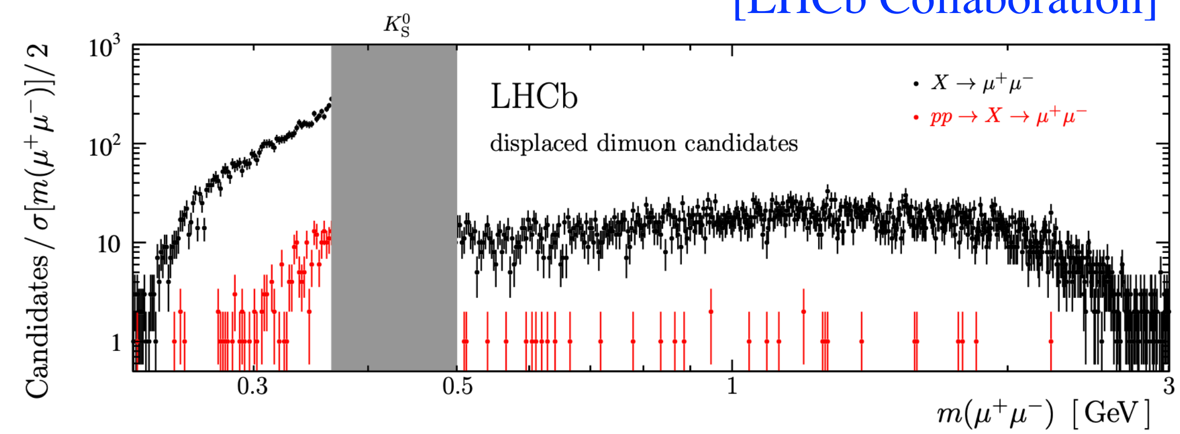
Z' mediation, CMS Scouting,
$m_{Z'} = 20$ GeV, $f_{\hat{\pi}} = 1$ GeV
Pushed up to O(1) PeV
1km
$\tau_{\hat{\pi}} = 10$m
10cm
1mm
EWPT
$Z+Z' \to$DS (1DV), 3 ab^{-1}
FCNC$_{B\text{-incl}}$, 3 ab^{-1}
$Z+Z' \to$DS (1DV), 101 fb^{-1}
FCNC$_{B\text{-incl}}$, 101 fb^{-1}
$Z+Z' \to$DS (2DV), 3 ab^{-1}
f_a [PeV]
$m_{\hat{\pi}}$ [GeV]

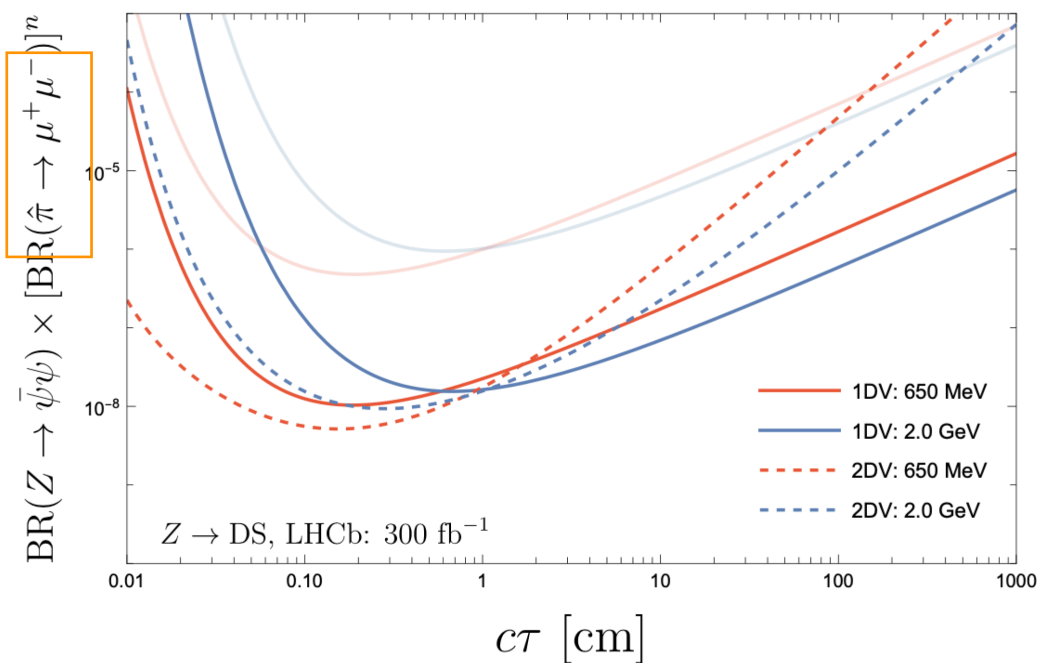
LHCb & HL-LHC

Low-mass displaced di-muon candidate search

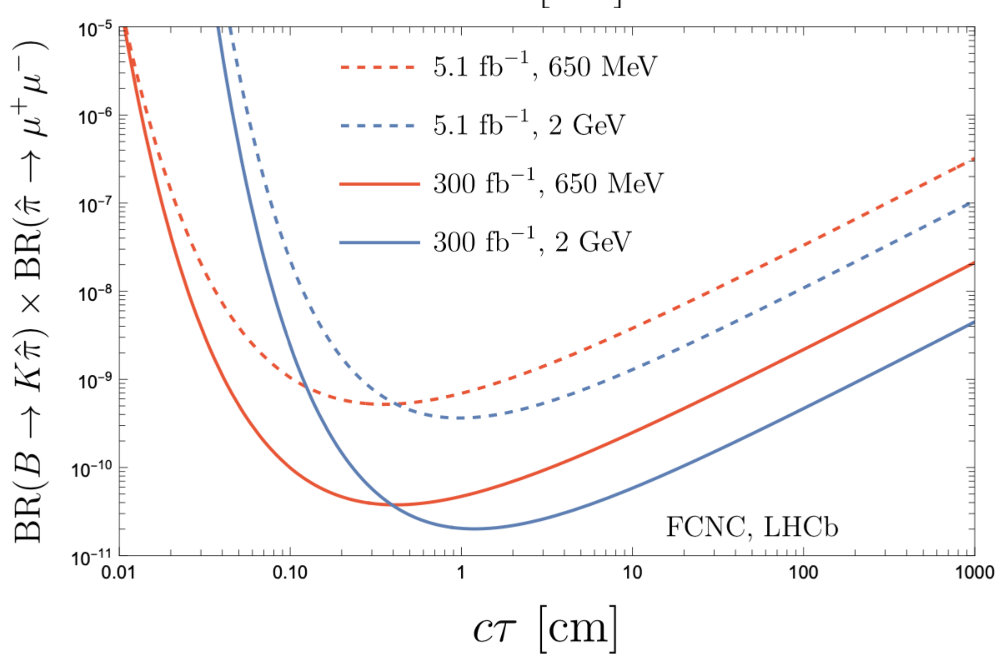
low trigger thresholds
high vertex resolutions

[LHCb Collaboration]





[P. Ilten, et al.]



Compared with CMS:

- Sensitive to a shorter lifetime
- Less bkg results in 2DV less improved
- Focus on the forward region

Large B production

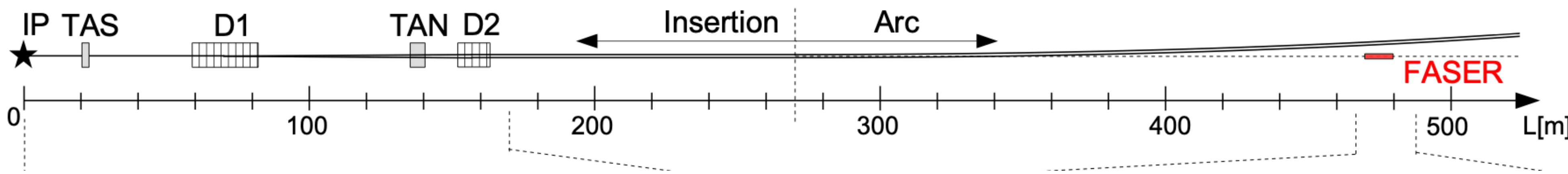
FCNC!

Far Detectors

- FASER(II)

[FASER Collaboration]

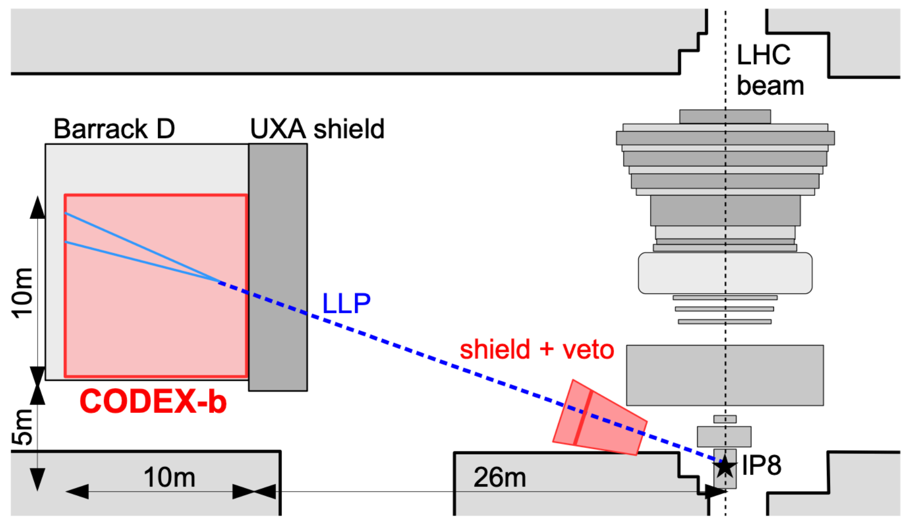
Collecting data now!



Forward; Cylinder;
In SM, only neutrino & muon reach!

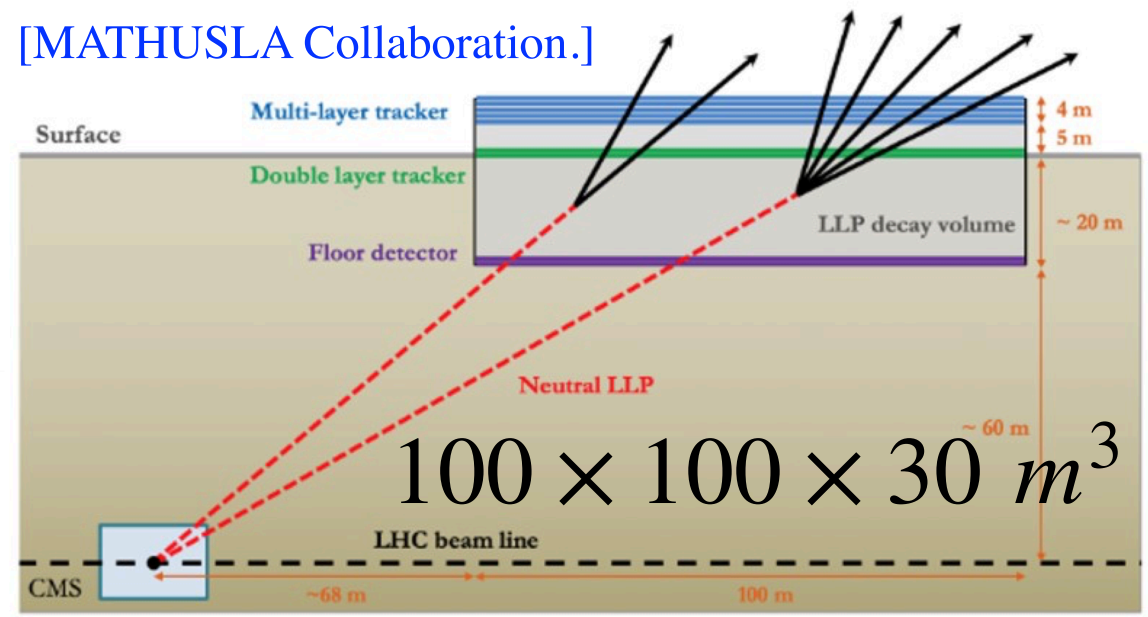
- Codex-b

[Berlin, and Kling.]



- MATHUSLA

[MATHUSLA Collaboration.]

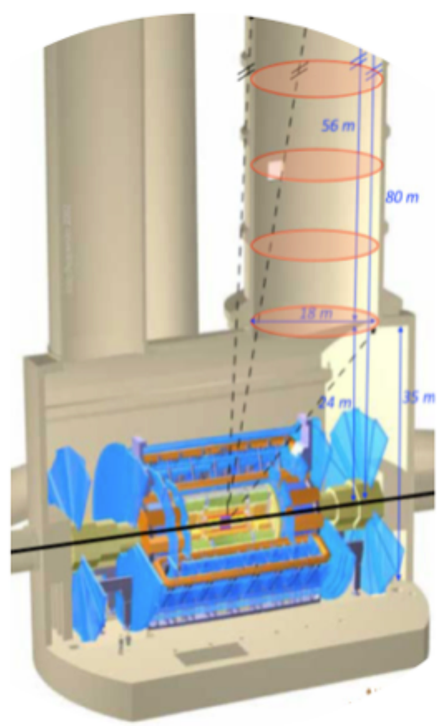


$$100 \times 100 \times 30\ m^3$$

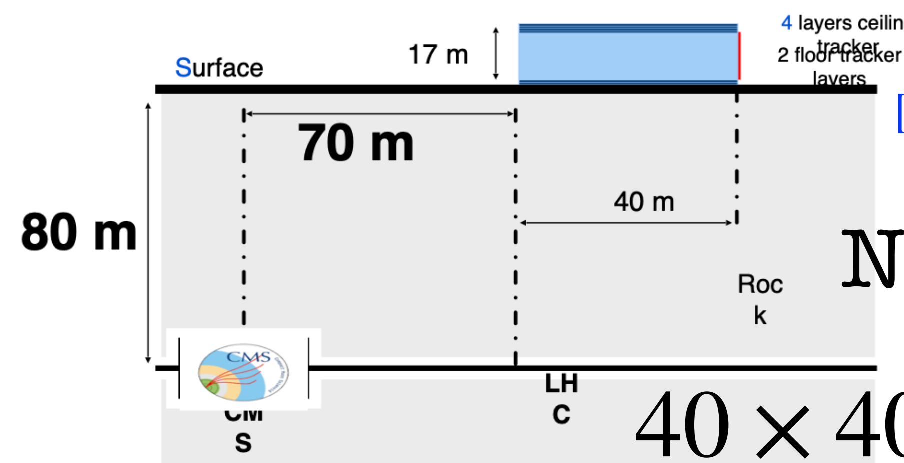
- ANUBIS

[ANUBIS Wiki]

Ceiling: a larger solid angle



Shaft configuration



Side view

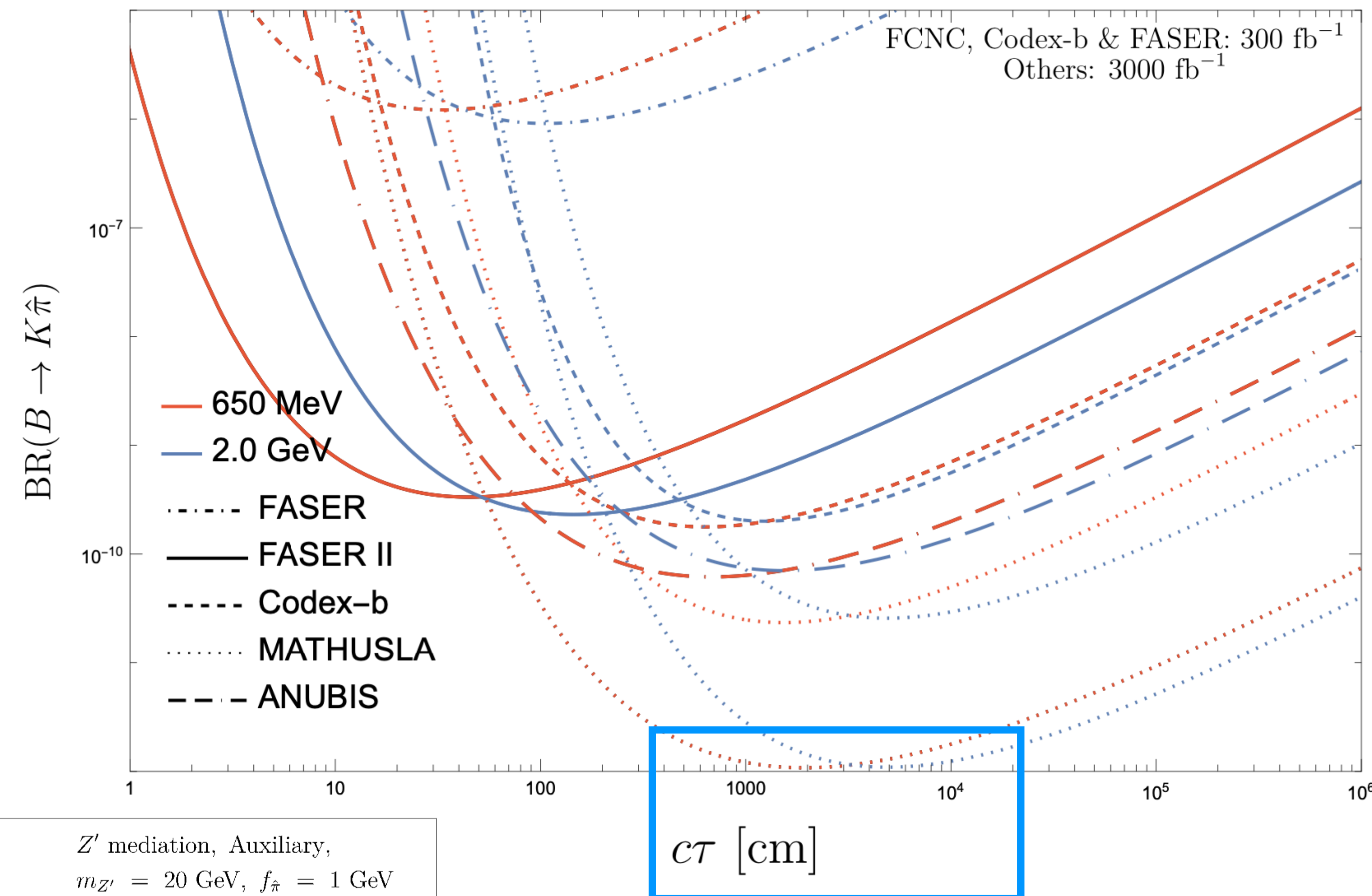
[MATHUSLA Status]

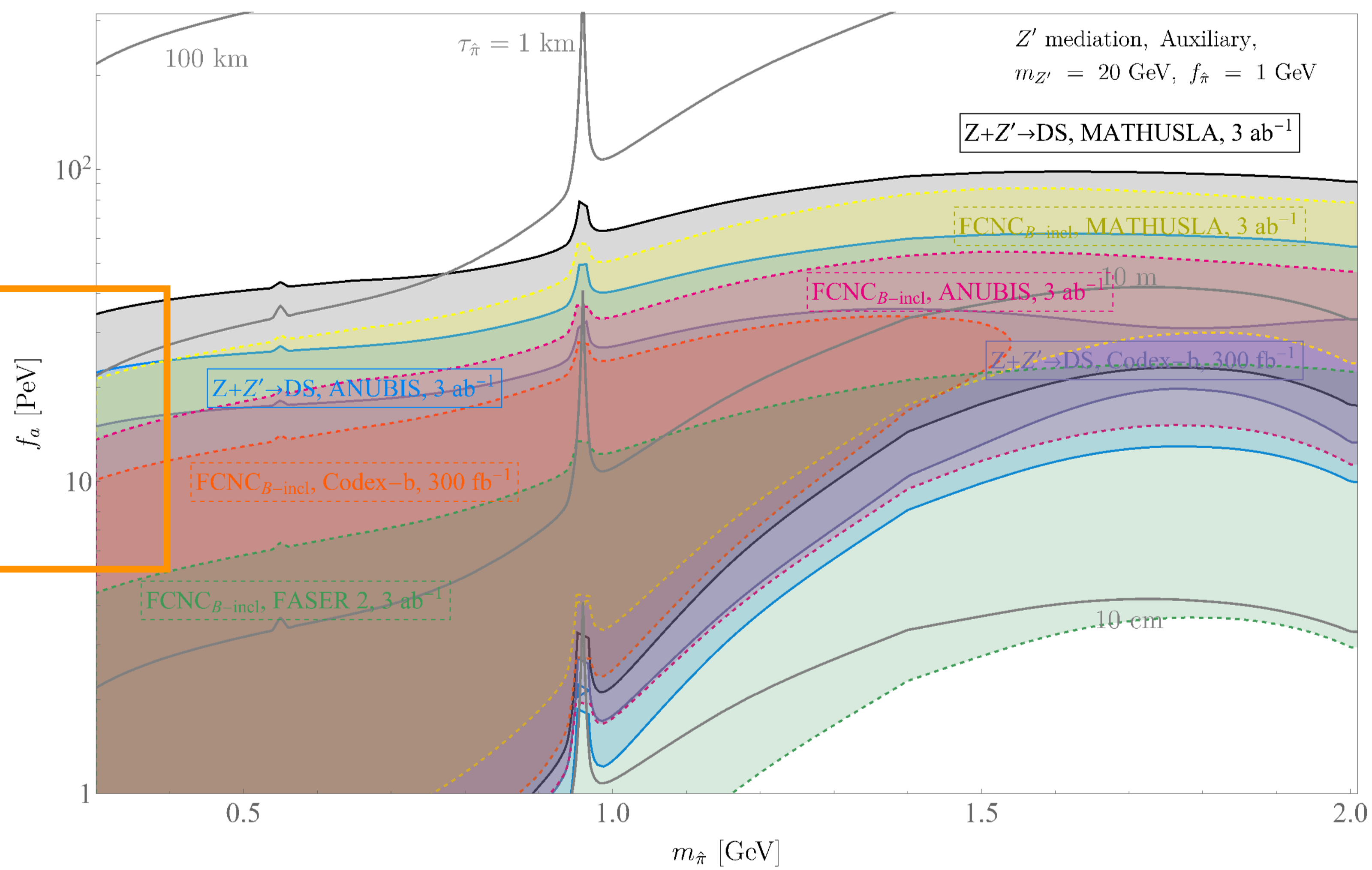
New Design

$$40 \times 40 \times 17\ m^3$$

Far Detectors

A longer lifetime





A larger f_a , up to $\mathcal{O}(10)$ PeV

Collider Simulation & Analysis

Simulation: All done with Pythia 8

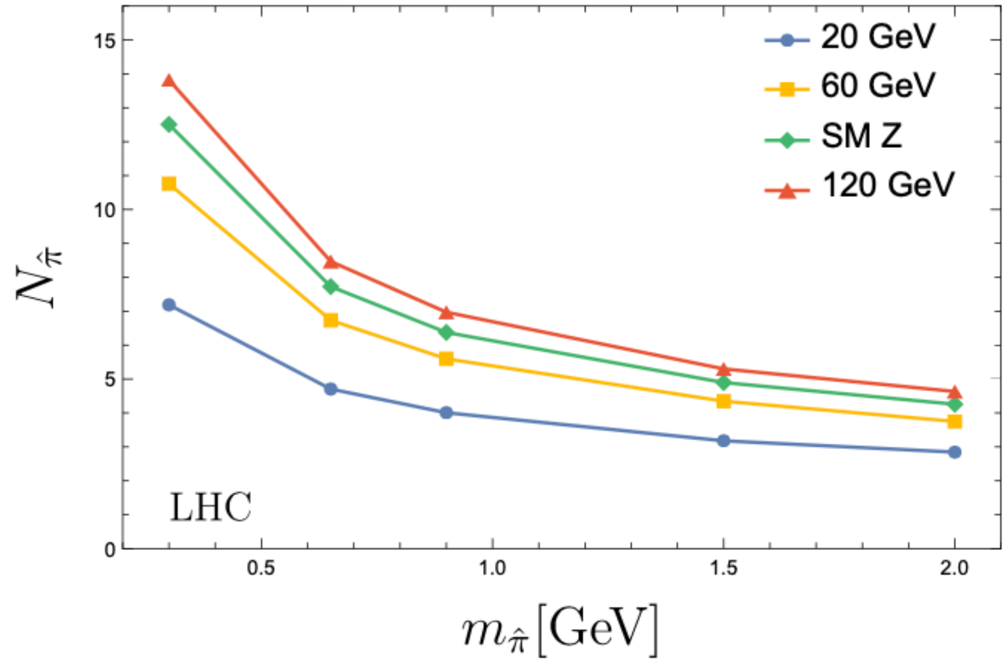
- with Hidden Valley module

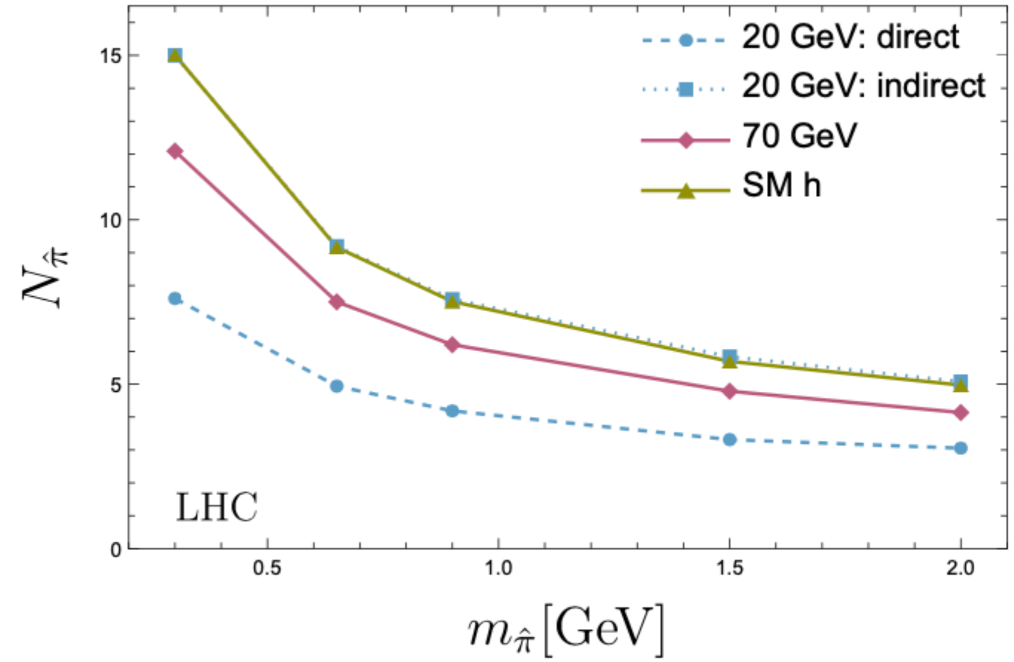
```
pythia.readString("HiddenValley:aLund=0.1");
pythia.readString("HiddenValley:bmqv2=2.0");
pythia.readString("HiddenValley:rFactqv=1.0");
```

- systematic uncertainties due to our unknown to dark hadronisation/showering params

Pion Multiplicity

If scalar too light: $\phi \to \bar{\psi}\psi$ *direct*
$h \to \phi(\to \bar{\psi}\psi)\phi$ *indir*





Analysis: Bkg estimation / N=3

- decay vertex in the detector
- decay products being collected

Opportunities at (HL-)LHC

ATLAS/CMS: larger luminosity and decay vessel.

A dedicated dimuon trigger stream (scouting)

[CMS Collaboration]

Data Scouting in CMS

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Online data taking

Data scouting in collider experiments refers to the use of physics objects reconstructed online during data taking to perform searches and measurements. The technique, pioneered by the CMS experiment, allows events to be recorded for analyis at a rate of several additional kHz with negligible impact on total data volume. Dijet resonance searches have used data scouting to probe resonance masses far lower than those explorable with a standard offline physics analysis, and new developments for LHC Run II enable a wider range of analyses to take advantage of this new trigger paradigm. We describe the scouting technique, give an overview of its past use in CMS, and provide details on the implementation of the scouting streams being used in Run II. We also show results from the first scouting-based physics analysis with 13 TeV data.

[D. Anderson]

Opportunities at (HL-)LHC: trigger efficiency benchmarks

CMS

ℓ_{xy} (cm) vs. p_t^{μ} (GeV)

ℓ_{xy}	3–5	5–8	8–10	10–15	>15 GeV
0–0.2	0.12	0.51	0.6	0.59	0.14
0.2–1	0.12	0.51	0.6	0.56	0.44
1–2.4	0.1	0.43	0.55	0.53	0.52
2.4–3.1	0.07	0.34	0.44	0.52	0.46
3.1–7	0.05	0.24	0.35	0.37	0.36
7–11	0.03	0.15	0.21	0.21	0.19
>11 cm	0	0	0	0	0

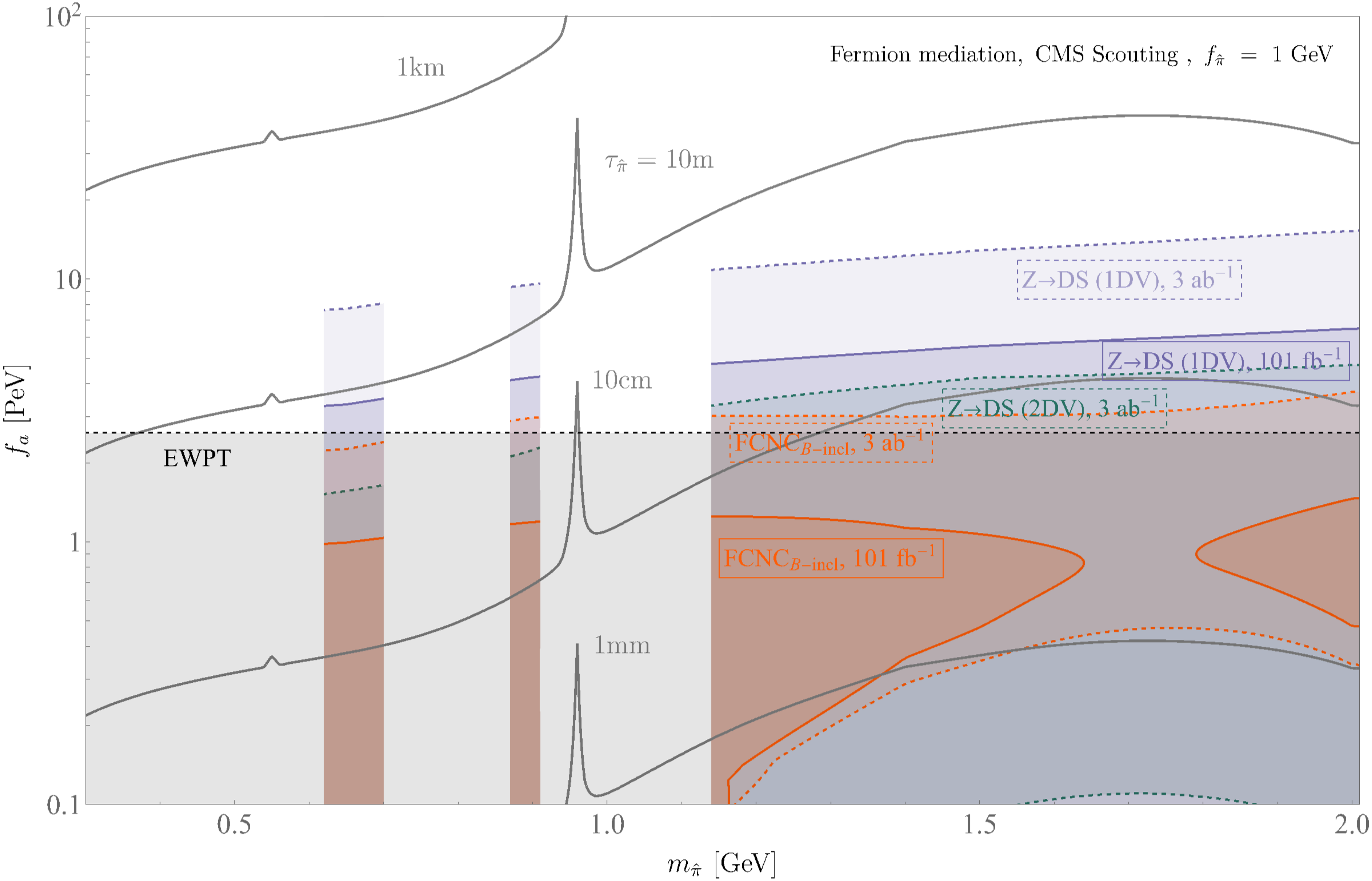
HL-LHC

ℓ_{xy}	3–5	5–8	8–10	10–15	>15 GeV
0–0.2	0.1	0.46	0.59	0.59	0.53
0.2–1	0.1	0.46	0.58	0.59	0.53
1–2.4	0.1	0.45	0.58	0.58	0.52
2.4–3.1	0.1	0.45	0.57	0.58	0.52
3.1–7	0.098	0.44	0.56	0.56	0.5
7–11	0.094	0.42	0.53	0.54	0.48
11–20	0.086	0.38	0.49	0.49	0.44
20–40	0.069	0.31	0.39	0.4	0.35
40–90	0.046	0.21	0.26	0.26	0.24
>90 cm	0.017	0.077	0.098	0.099	0.089

ℓ_{xy}	3–5	5–8	8–10	10–15	>15 GeV
0–0.2	0.1	0.46	0.59	0.59	0.53
0.2–1	0.1	0.46	0.59	0.59	0.53
1–2.4	0.1	0.46	0.58	0.59	0.53
2.4–3.1	0.1	0.46	0.58	0.59	0.52
3.1–7	0.098	0.44	0.56	0.56	0.5
7–11	0.088	0.39	0.5	0.5	0.45
11–20	0.064	0.29	0.36	0.37	0.33
20–40	0.028	0.12	0.16	0.16	0.14
40–90	0.0067	0.03	0.038	0.038	0.034
>90 cm	0.0035	0.016	0.02	0.02	0.018

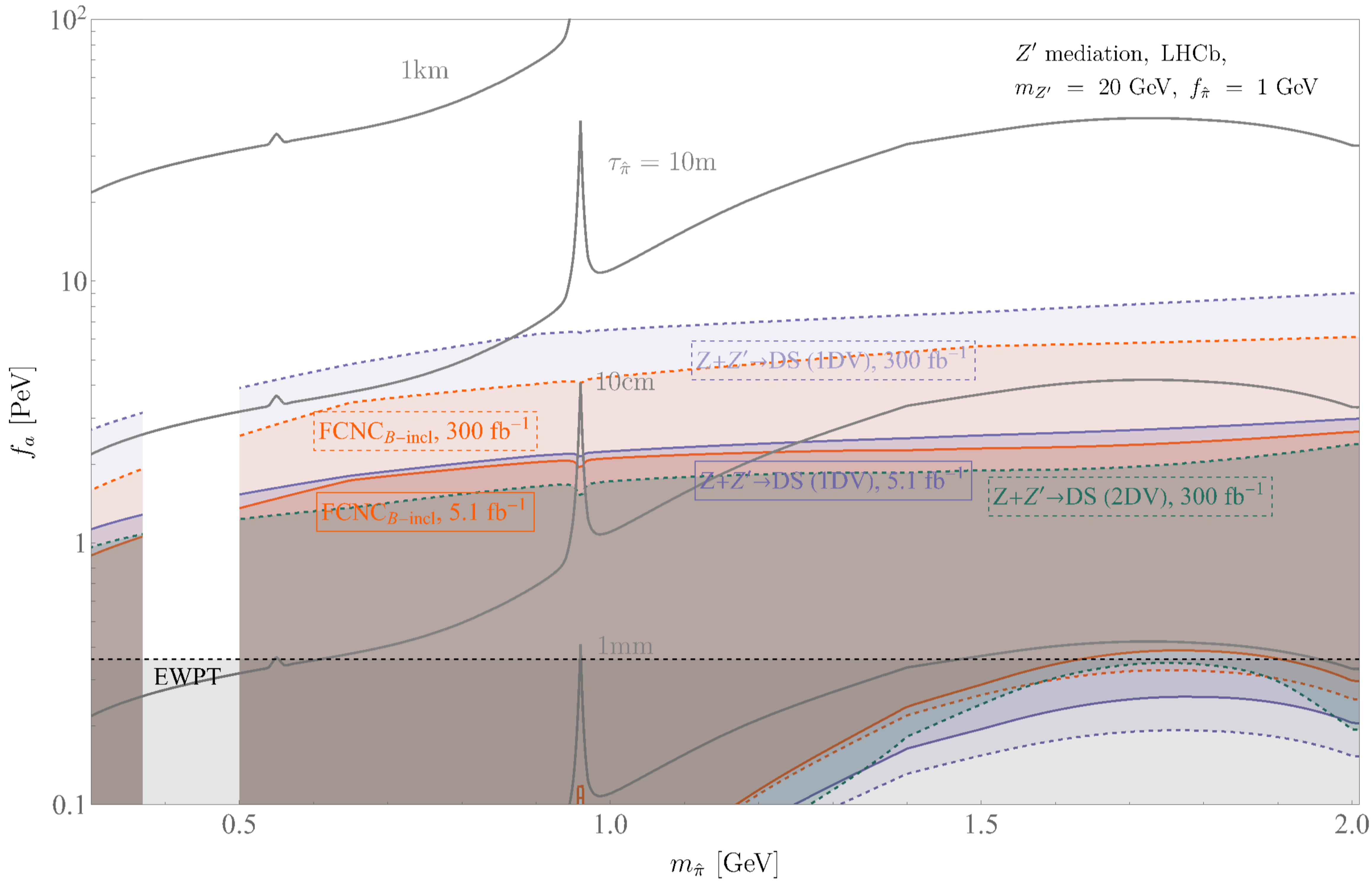
ℓ_{xy}	3–5	5–8	8–10	10–15	>15 GeV
0–0.2	0.1	0.46	0.59	0.59	0.53
0.2–1	0.1	0.46	0.59	0.59	0.53
1–2.4	0.1	0.45	0.57	0.58	0.51
2.4–3.1	0.096	0.43	0.54	0.55	0.49
3.1–7	0.079	0.35	0.45	0.45	0.4
7–11	0.047	0.21	0.27	0.27	0.24
11–20	0.016	0.073	0.093	0.094	0.084
20–40	<0.001	0.0042	0.0054	0.0054	0.0048
40–90	<0.001	<0.001	<0.001	<0.001	<0.001
>90 cm	<0.001	<0.001	<0.001	<0.001	<0.001

CMS & HL-LHC



Fermion mediation, CMS Scouting , $f_{\hat{\pi}}$ = 1 GeV
1km
$\tau_{\hat{\pi}}$ = 10m
10cm
1mm
EWPT
Z→DS (1DV), 3 ab^{-1}
Z→DS (1DV), 101 fb^{-1}
Z→DS (2DV), 3 ab^{-1}
$FCNC_{B-incl}$, 3 ab^{-1}
$FCNC_{B-incl}$, 101 fb^{-1}
f_a [PeV]
$m_{\hat{\pi}}$ [GeV]
10^2
10
1
0.1
0.5
1.0
1.5
2.0

LHCb & HL-LHC



Z' mediation, LHCb,
$m_{Z'}$ = 20 GeV, $f_{\hat{\pi}}$ = 1 GeV
1km
$\tau_{\hat{\pi}} = 10$m
10cm
1mm
EWPT
FCNC$_{B\text{-incl}}$, 300 fb^{-1}
FCNC$_{B\text{-incl}}$, 5.1 fb^{-1}
Z+Z′→DS (1DV), 300 fb^{-1}
Z+Z′→DS (1DV), 5.1 fb^{-1}
Z+Z′→DS (2DV), 300 fb^{-1}
f_a [PeV]
$m_{\hat{\pi}}$ [GeV]
10^2
10
1
0.1
0.5
1.0
1.5
2.0

Z-Factory: Tera-Z

Kinematic and geometric cuts

$$p_t^{\mu\mu} > 2 \text{ GeV}, \quad |\eta^{\mu\mu}| < 5$$

$$|p|^{\mu_i} > 10 \text{ GeV}, \quad p_t^{\mu_i} > 0.5 \text{ GeV}, \quad |\eta^{\mu_i}| < 5 \quad (i = 1, 2)$$

$$0.5 < l_{xy} < 100 \text{ cm}$$