

DARK SECTORS

THE **WHYS** AND **HOWS** OF **LIFE AFTER WIMPS**

Flip Tanedo

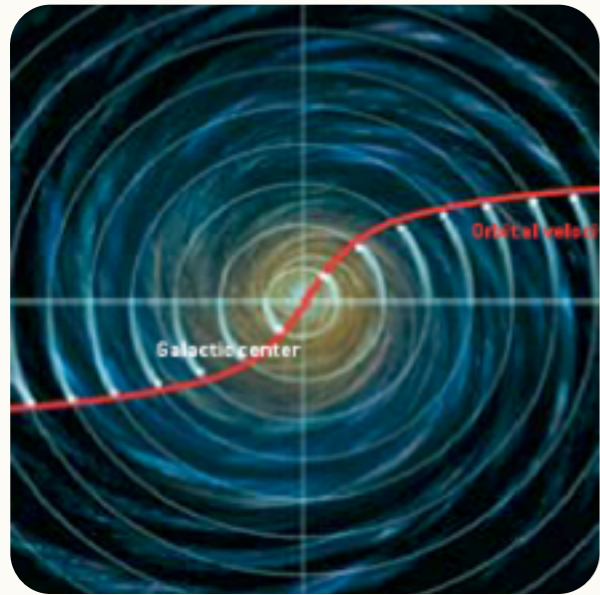
UC Riverside Particle Theory



3 Feb 2017 Washington D.C.

APS Topical Group on Hadronic Physics

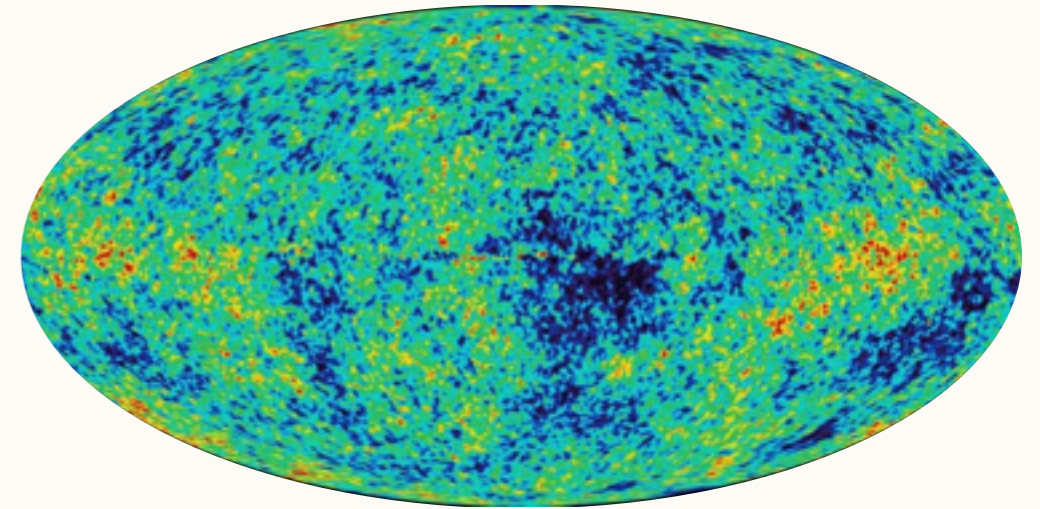
Astro + Cosmo: Dark Matter Exists



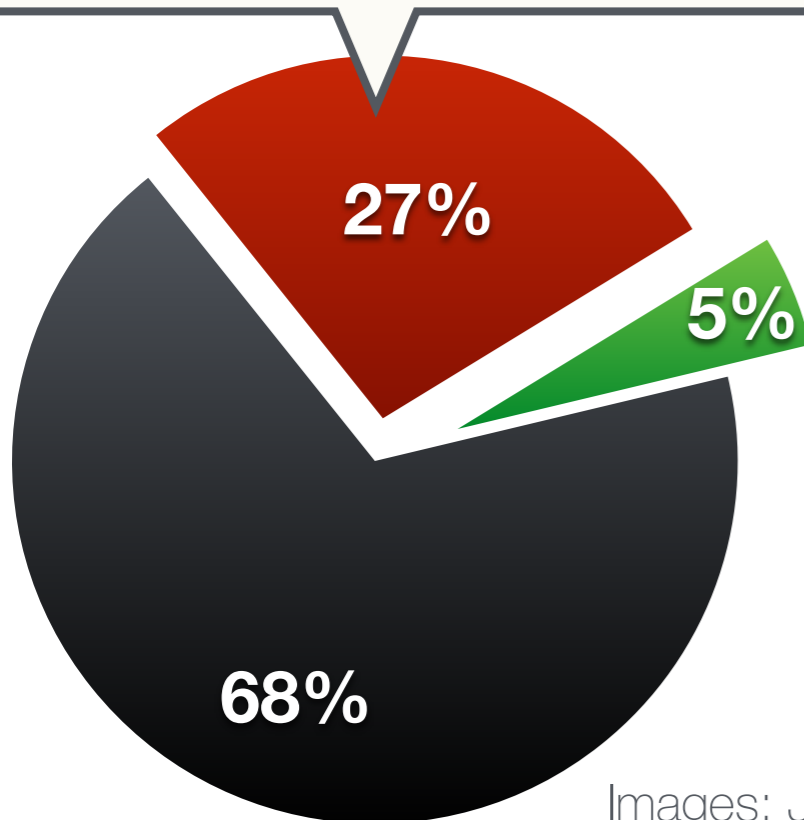
GALACTIC ROTATION CURVES



GRAVITATIONAL LENSING



COSMIC MICROWAVE BACKGROUND



Standard Model is **not** complete

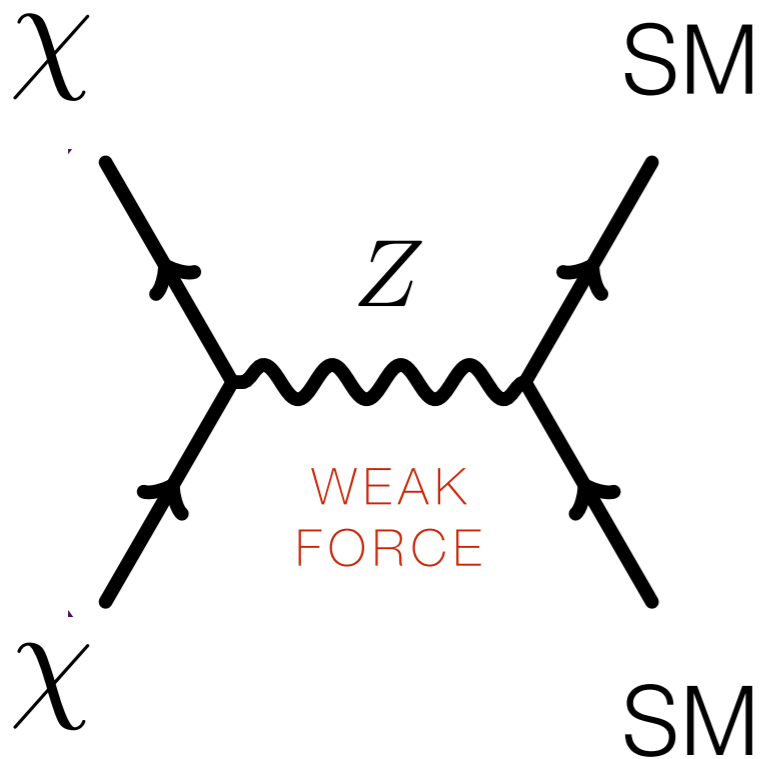
Images: Jeff Filippini (Berkeley Cosmology 2005), NASA APOD 2006, NASA WMAP

Weakly-Interacting Massive Particles

INTERACTS VIA WEAK FORCE (**W** and **Z** BOSONS)

Explains: **Why is there so much dark matter around?**

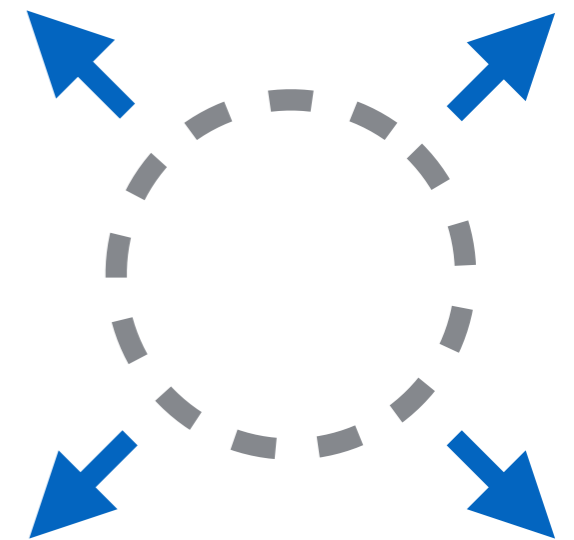
“WEAK SCALE” MASS
~100 GeV



OBSERVED **AMOUNT OF DARK MATTER** TODAY

$$\Omega_{\chi} h^2 \sim \frac{0.1 \text{ pb}}{\langle \sigma_{\text{ann}} v \rangle}$$

“WEAK SCALE”
ANNIHILATION RATE



dark matter annihilation

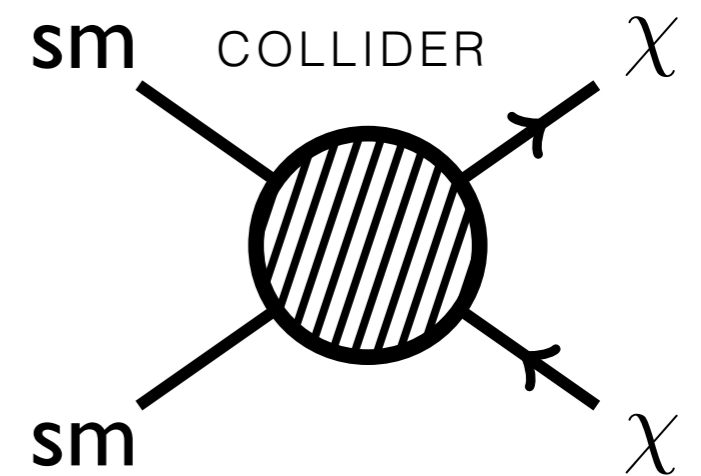
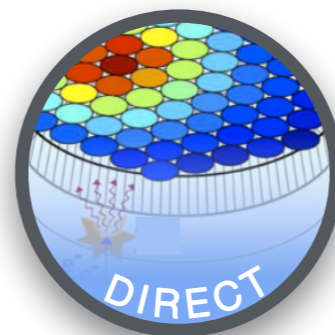
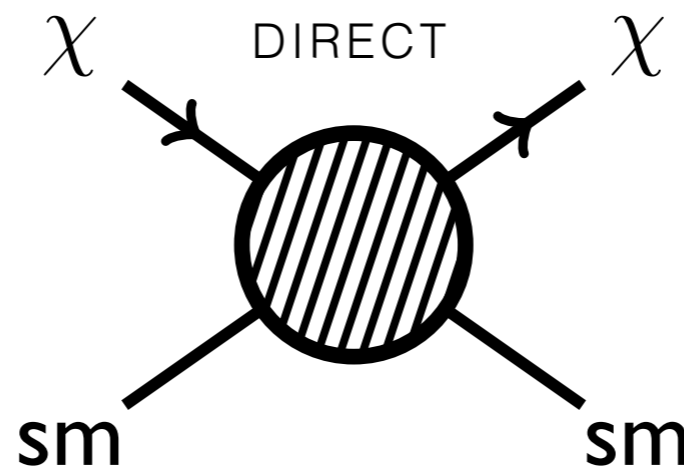
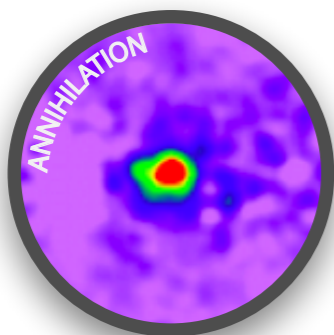
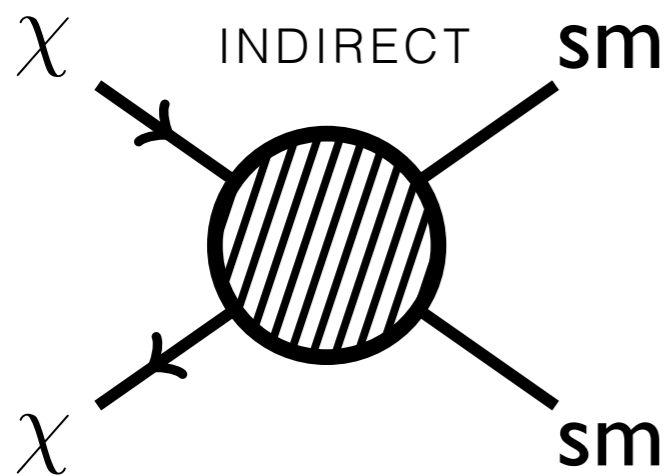
vs.

expansion of universe

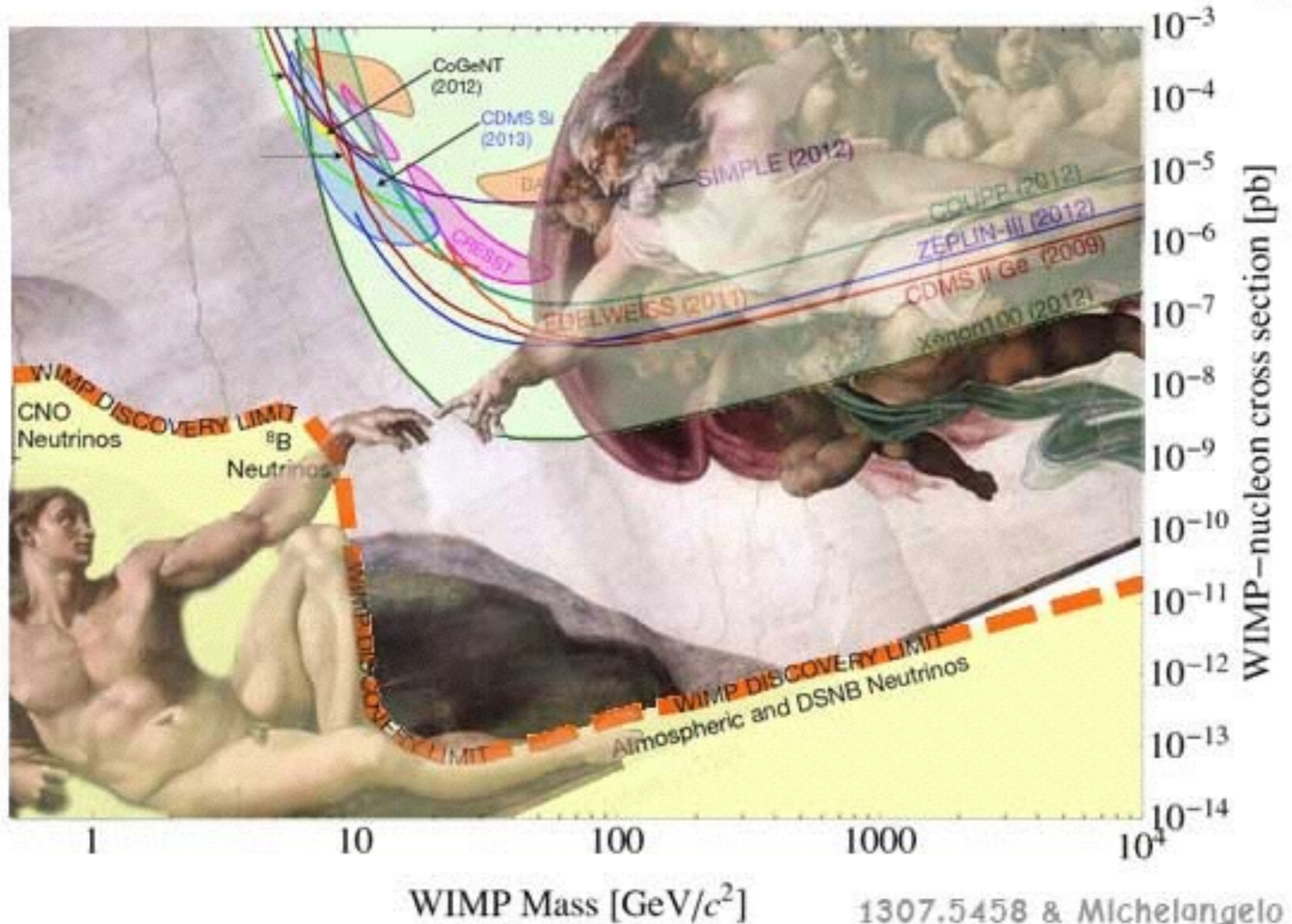
WIMP Complementarity



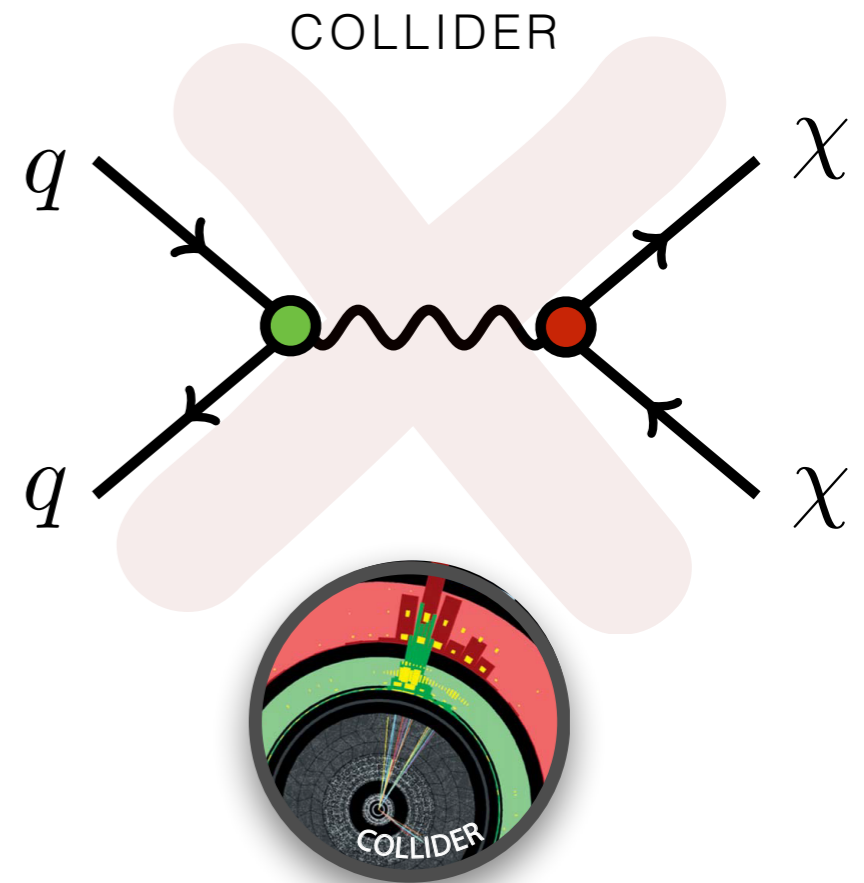
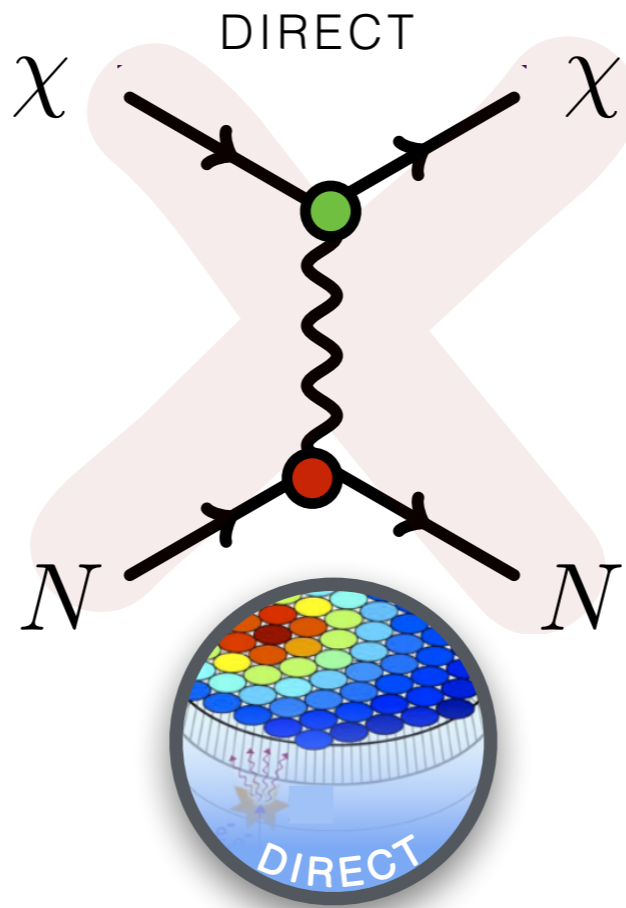
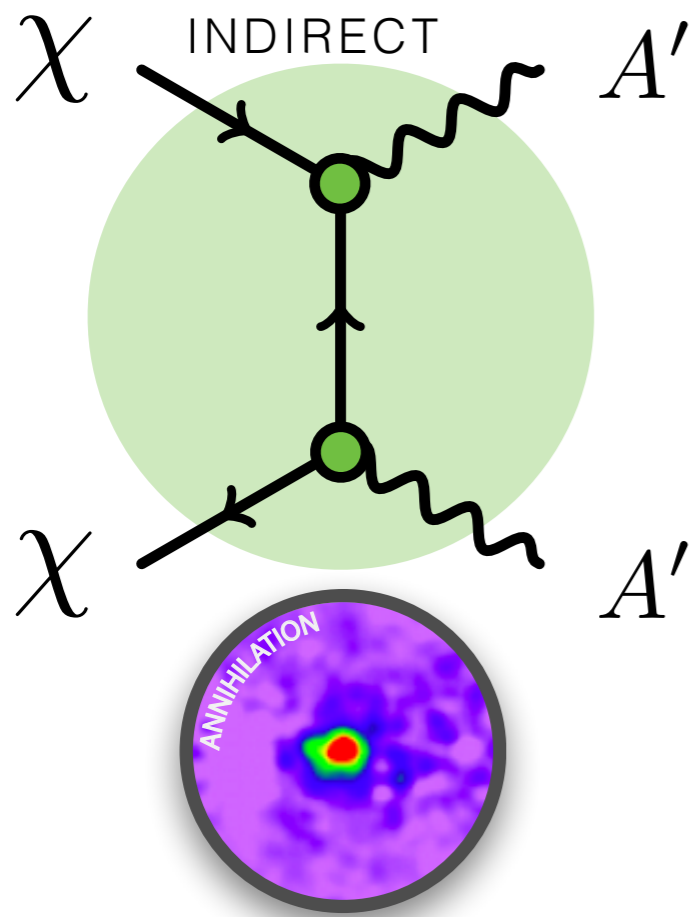
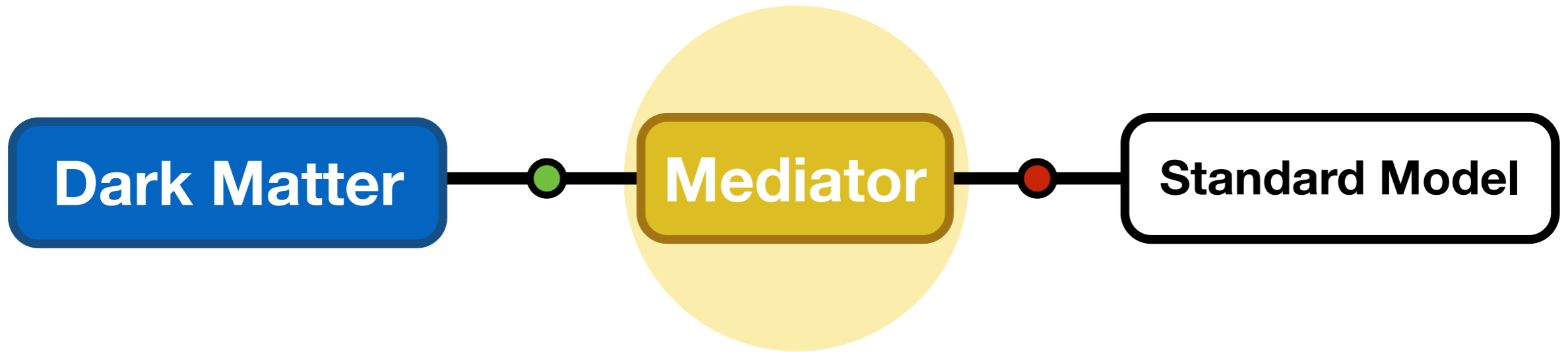
Dark matter searches related by crossing symmetry:



Tough Times for WIMPs



WIMP Searches vs. Light Mediators



can keep thermal relic!

Renormalizable Portals

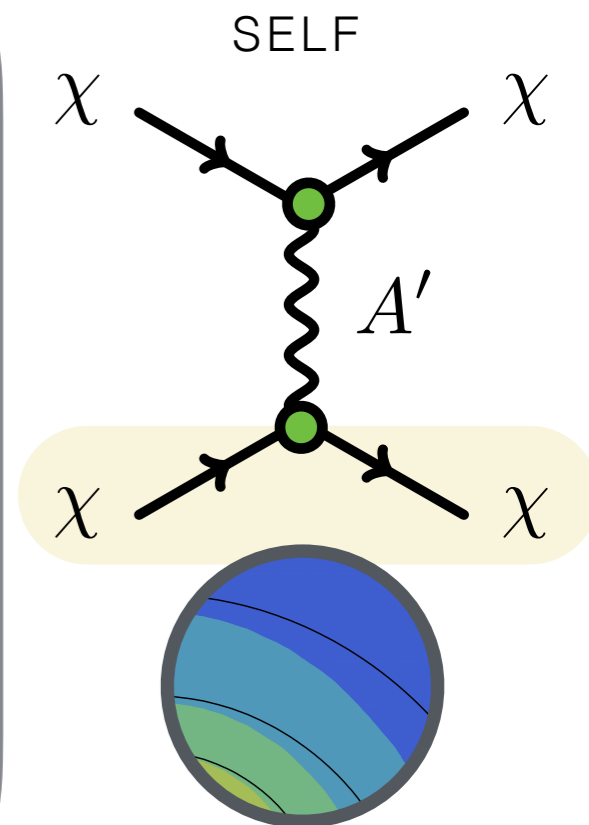
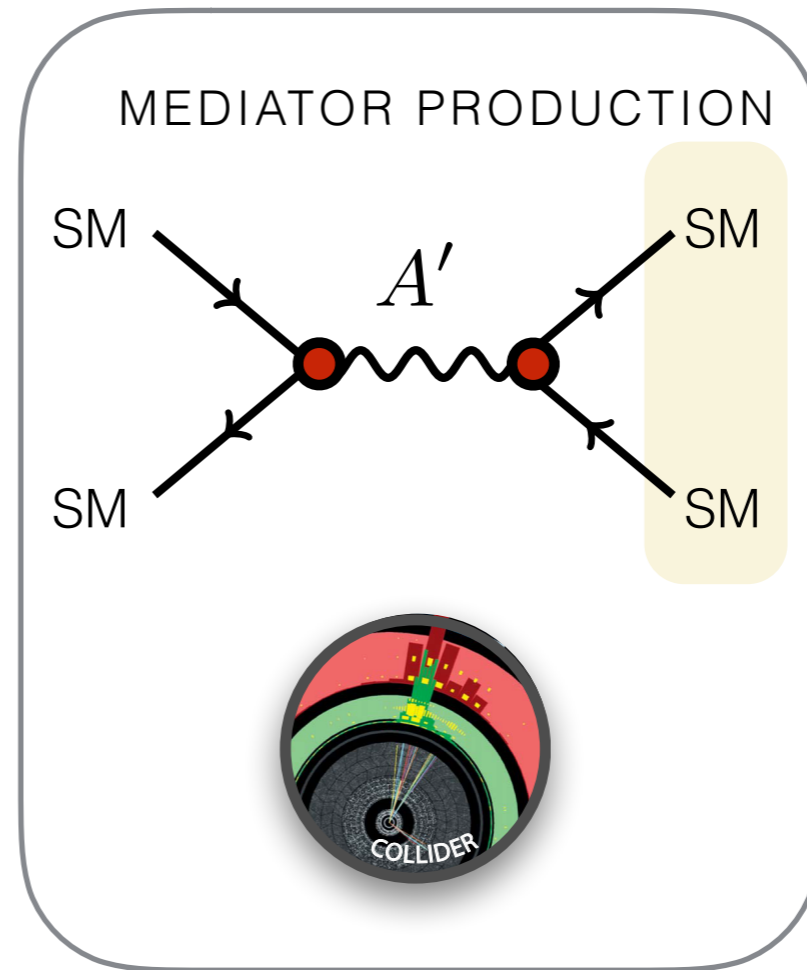
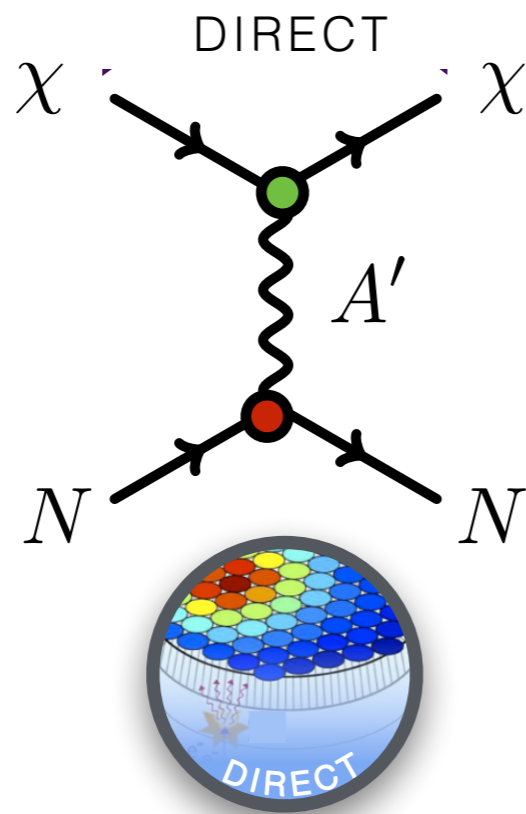
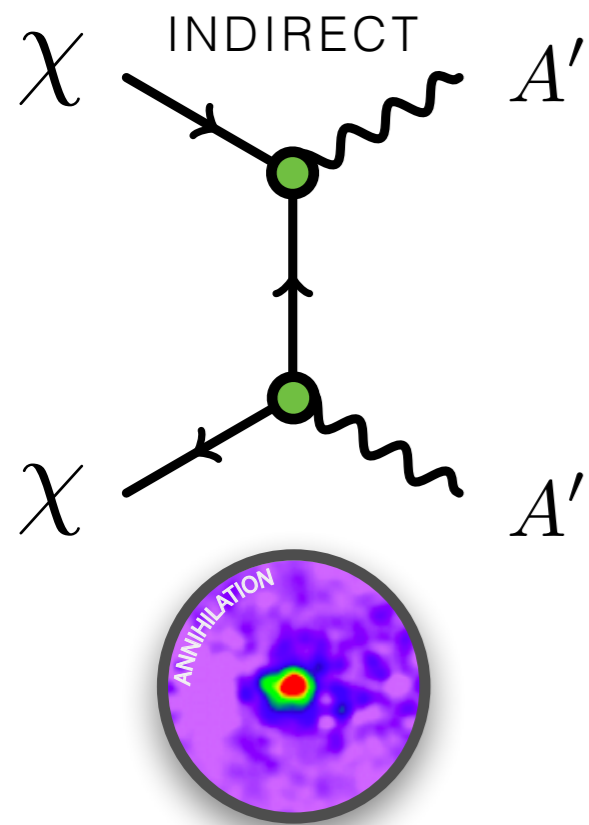


BENCHMARK IN THIS TALK



... plus variations of each portal

New Searches with Light Mediators

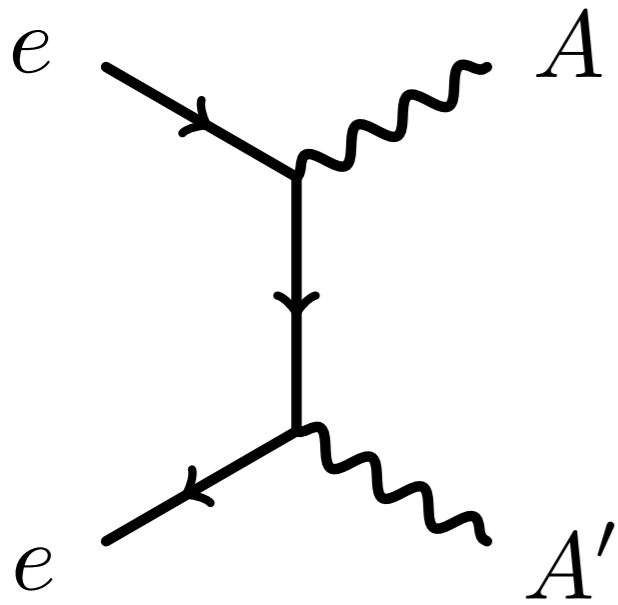


accelerators

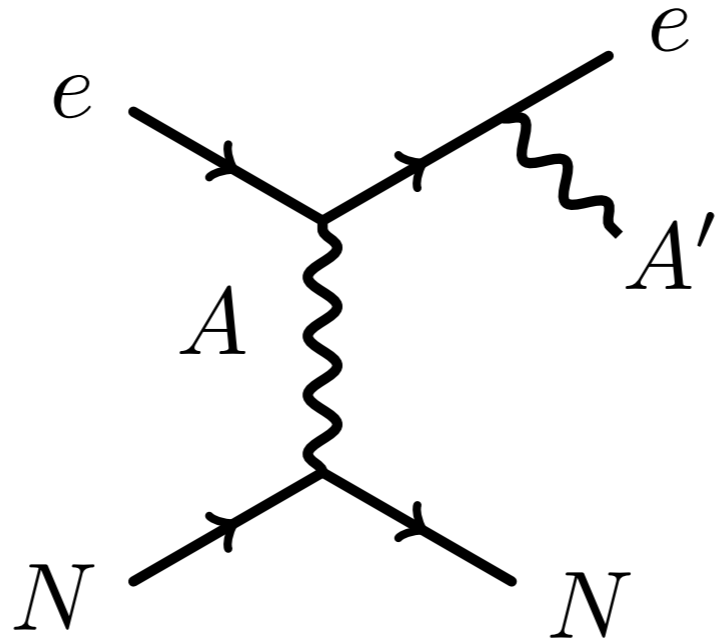
astro

Step 1: Mediator Production

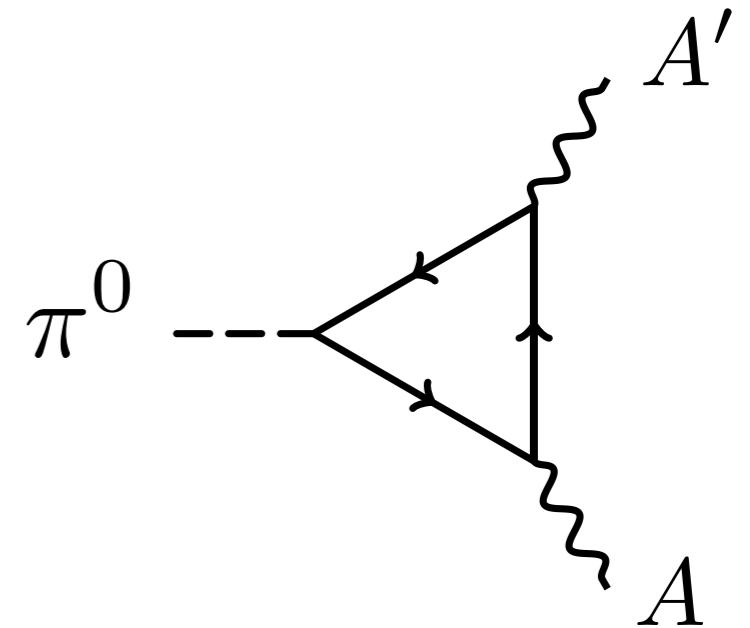
EXAMPLES OF LIGHT MEDIATOR PRODUCTION STRATEGIES



annihilation



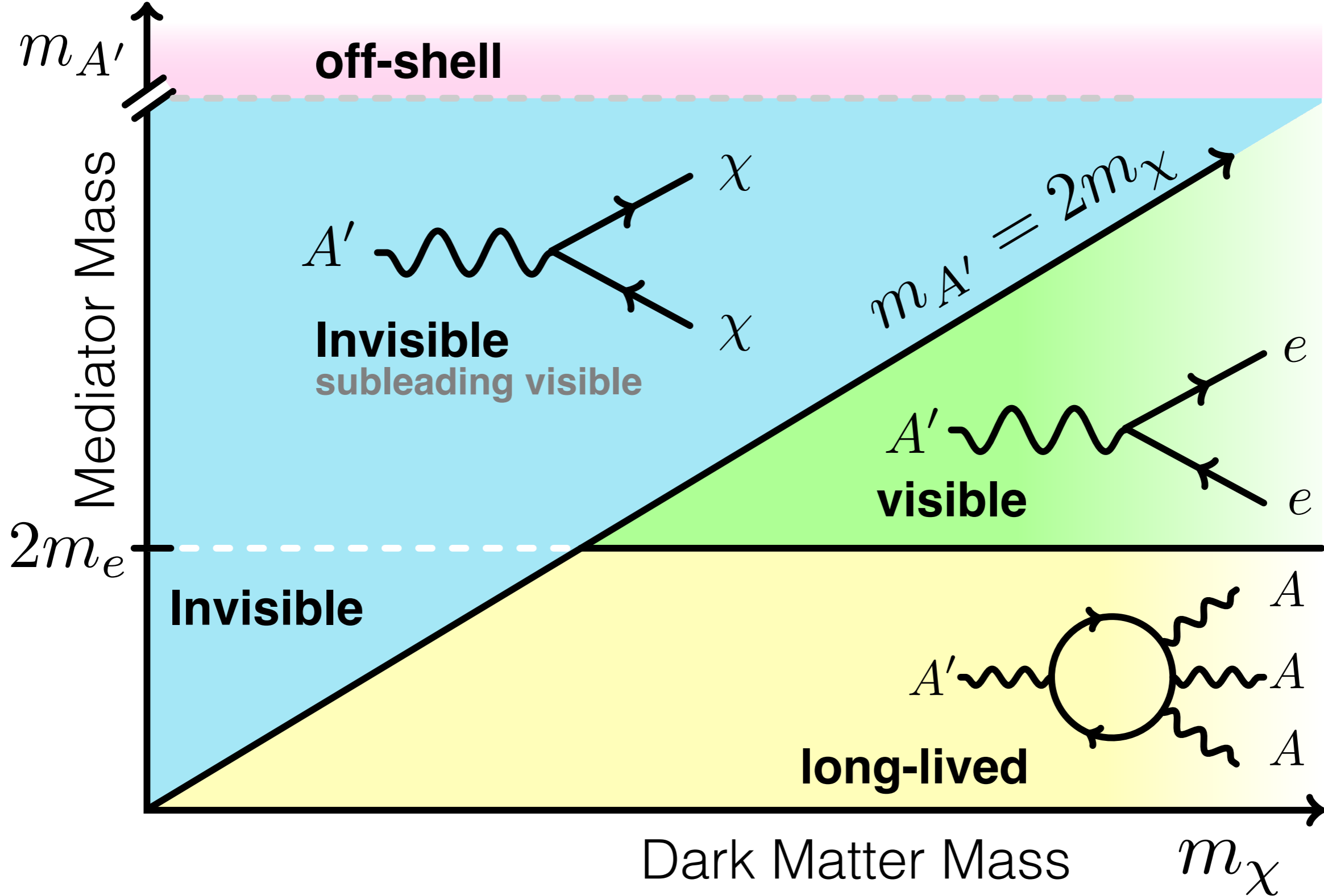
bremsstrahlung



meson decay

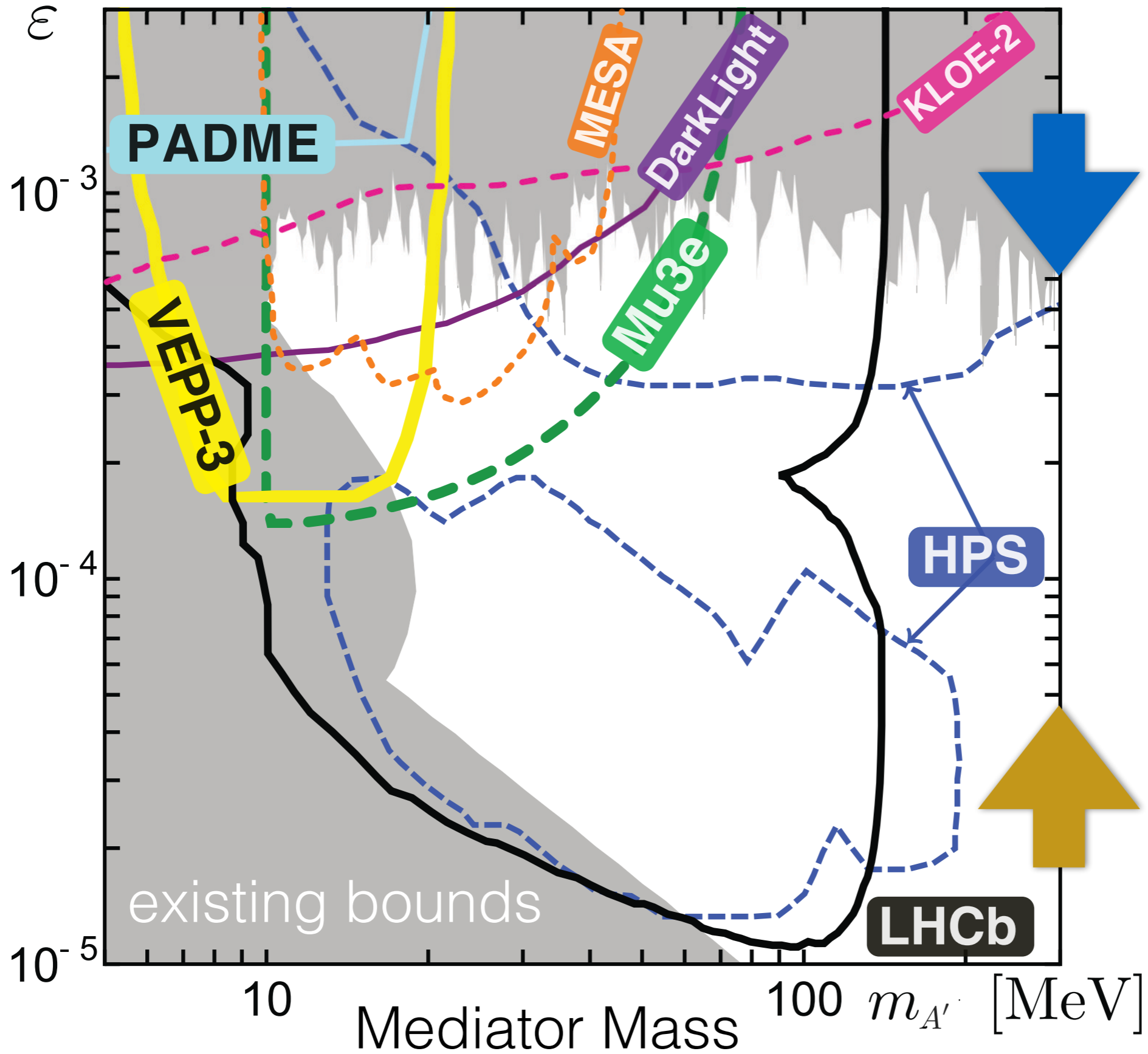
Others: Drell-Yan, nuclear transitions, Higgs decays, ...

Step 2: Mediator Decay



Adapted from Natalia Toro, Dark Sectors 2017 (1608.03591)

Interaction with Standard Model



prompt

LIMITED BY STATISTICS

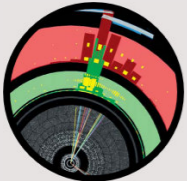
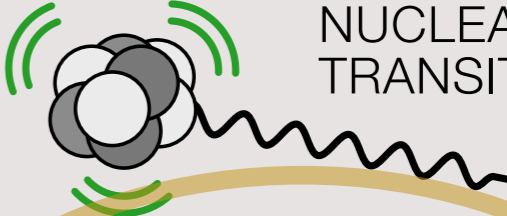
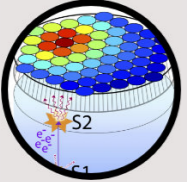
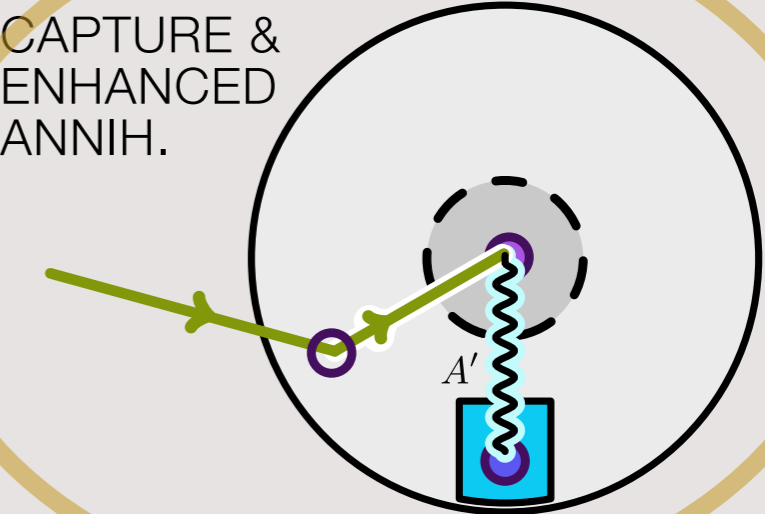
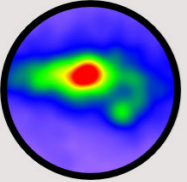
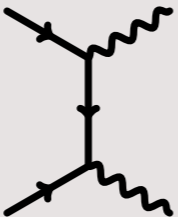
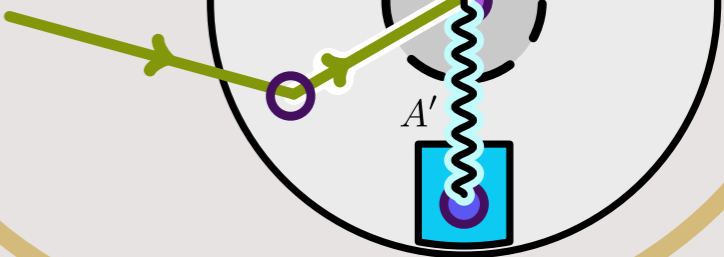
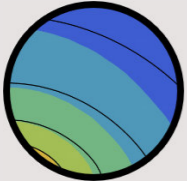
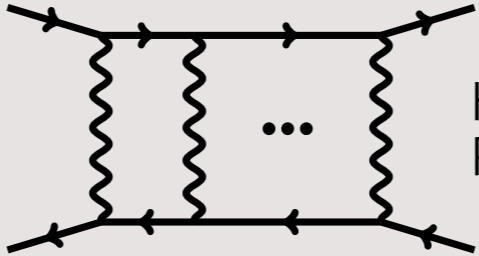

LIMITED BY VERTEXING

displaced vertex

Adapted from 1608.08632, 1608.03591, N. Toro at Dark Sectors 2017

Experiment	Lab	Production	Detection	Vertex	Mass(MeV)	Mass Res. (MeV)	Beam	Ebeam (GeV)	Ibeam or Lumi	Machine	Ist Run	Next Run
APEX	JLab	e-brem	$\ell^+\ell^-$	no	65 – 600	0.5%	e^-	1.1–4.5	150 μ A	CEBAF(A)	2010	2018
A1	Mainz	e-brem	e^+e^-	no	40 – 300	?	e^-	0.2–0.9	140 μ A	MAMI	2011	–
HPS	JLab	e-brem	e^+e^-	yes	20 – 200	1–2	e^-	1–6	50–500 nA	CEBAF(B)	2015	2018
DarkLight	JLab	e-brem	e^+e^-	no	< 80	?	e^-	0.1	10 mA	LERF	2016	2018
MAGIX	Mainz	e-brem	e^+e^-	no	10 – 60	?	e^-	0.155	1 mA	MESA	2020	–
NA64	CERN	e-brem	e^+e^-	no	1 – 50	?	e^-	100	2×10^{11} EOT/yr	SPS	2017	2022
Super-HPS	SLAC	e-brem	vis	yes	< 500	?	e^-	4 – 8	1 μ A	DASEL	?	?
(TBD)	Cornell	e-brem	e^+e^-	?	< 100	?	e^-	0.1-0.3	100 mA	CBETA	?	?
VEPP3	Budker	annih	invis	no	5 – 22	1	e^+	0.500	$10^{33} \text{ cm}^{-2}\text{s}^{-1}$	VEPP3	2019	?
PADME	Frascati	annih	invis	no	1 – 24	2 – 5	e^+	0.550	$\leq 10^{14} e^+\text{OT}/\text{y}$	Linac	2018	?
MMAPS	Cornell	annih	invis	no	20 – 78	1 – 6	e^+	6.0	$10^{34} \text{ cm}^{-2}\text{s}^{-1}$	Synchr	?	?
KLOE 2	Frascati	several	vis/invis	no	< 1.1 GeV	1.5	e^+e^-	0.51	$2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$	DA ϕ NE	2014	–
Belle II	KEK	several	vis/invis	no	$\lesssim 10 \text{ GeV}$	1 – 5	e^+e^-	4 \times 7	$1 \sim 10 \text{ ab}^{-1}/\text{y}$	Super-KEKB	2018	–
SeaQuest	FNAL	several	$\mu^+\mu^-$	yes	$\lesssim 10 \text{ GeV}$	3 – 6%	p	120	$10^{18} \text{ POT}/\text{y}$	MI	2017	2020
SHIP	CERN	several	vis	yes	$\lesssim 10 \text{ GeV}$	1 – 2	p	400	$2 \times 10^{20} \text{ POT}/5\text{y}$	SPS	2026	–
LHCb	CERN	several	$\ell^+\ell^-$	yes	$\lesssim 40 \text{ GeV}$	~ 4	pp	6500	$\sim 10 \text{ fb}^{-1}/\text{y}$	LHC	2010	2015

Other Searches for Mediators

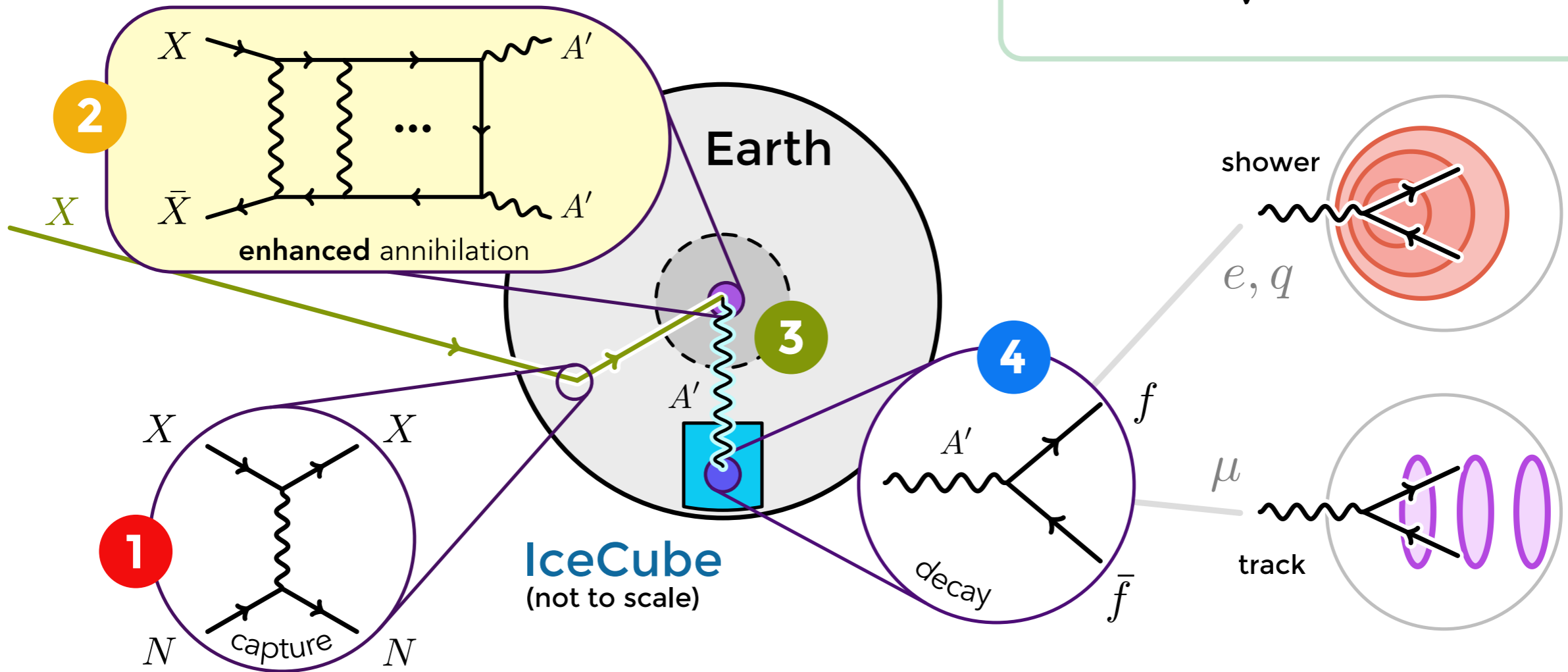
INTERACTION	WIMP SEARCH	LIGHT MEDIATORS	EXAMPLES OF NOVEL SEARCHES
 <p>PRODUCTION</p>	<p>COLLIDER: MISSING ENERGY</p>	<p>BEAM DUMP, FIXED-TARGET, MESON DECAY</p>	 <p>NUCLEAR TRANSITIONS</p>
 <p>SCATTERING</p>	<p>DIRECT DETECTION</p>	<p>RECOIL SPECTRUM</p>	 <p>CAPTURE & ENHANCED ANNIH.</p>
 <p>ANNIHILATION</p>	<p>INDIRECT DETECTION</p>	 <p>ANNIHILATION TO ON-SHELL MEDIATORS</p>	 <p>DISK STABILITY</p>
 <p>SELF-INT.</p>	<p>N/A</p>	 <p>HALO PROFILE</p>	 <p>HALO PROFILE</p>

Example: Earth Capture

WIMPs are never in equilibrium
Mediators change everything

EQUILIBRIUM TIME

$$\tau = \frac{1}{\sqrt{C_{\text{cap}} C_{\text{ann}}}}$$



$$\dot{N}_\chi = C_{\text{cap}} - C_{\text{ann}} N_\chi^2$$

Feng, Smolinsky, Tanedo (1509.07525)

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DARK SECTORS

Conclusion

Light mediators **avoid the tightest WIMP bounds** while offering **new search opportunities**

Well motivated (renormalizable portals), permits thermal freeze out, compatible with many classes of new physics...

REFERENCE AND UPCOMING WORKSHOP

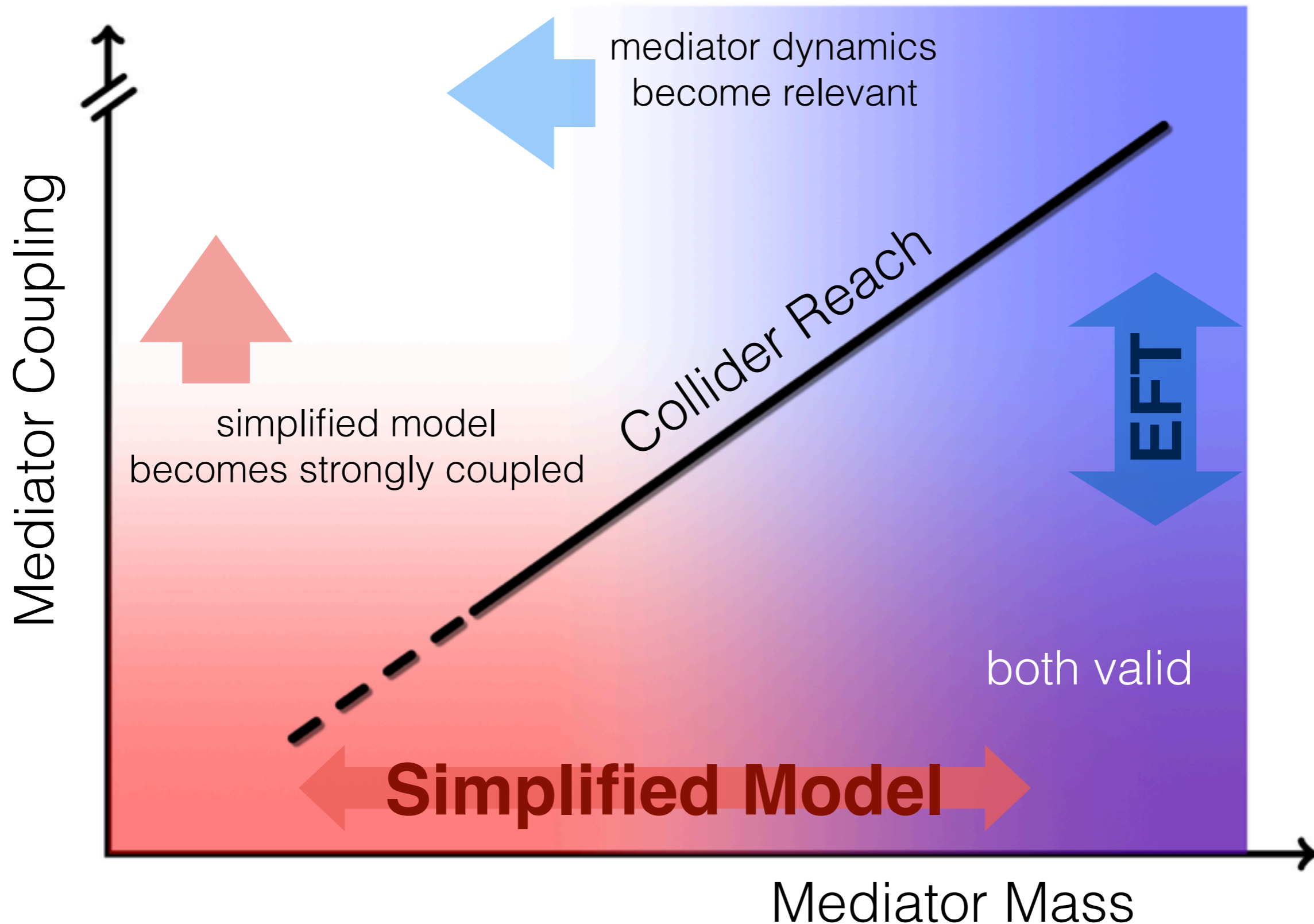
- Useful reference: 1608.08632 (Dark Sectors 2016 report)
- US Cosmic Vision: New Ideas in Dark Matter (UMD 23 - 25 March)

OTHER DIRECTIONS BEYOND A VANILLA WIMP

primordial black holes (no new DM particle), low-mass/axion/axion-like dark matter, asymmetric dark matter, non-thermal/freeze-in, strongly interacting massive particles (3-to-2 annihilation), inelastic, different spins, strong dynamics, ...

Extra Slides

EFT vs. Simplified Model



Adapted from Tim Tait, UCLA DM 2016