New tools for Indirect Detection in Generalized Dark Matter Models

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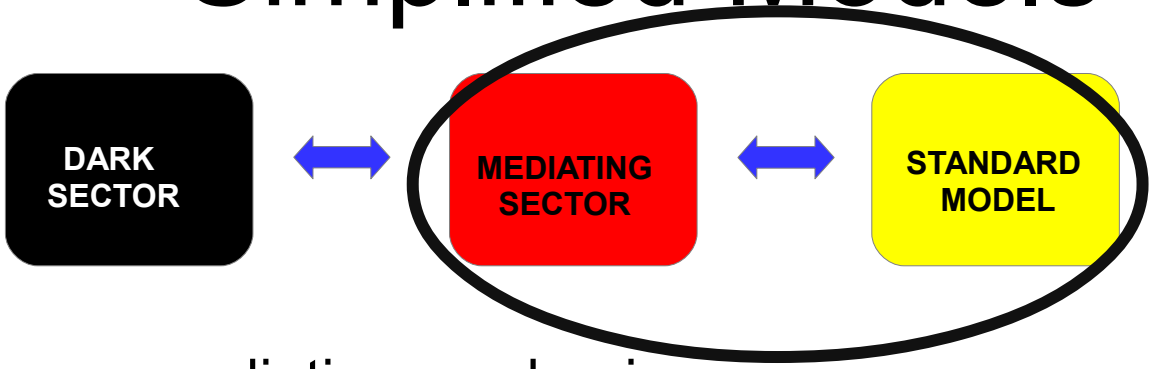
Coupling to the Dark Sector

Effective operators

Obfuscates Mediating sector, replaced with general scale, Captures kinematics of coupling to SM

Limited range of validity

Simplified Models

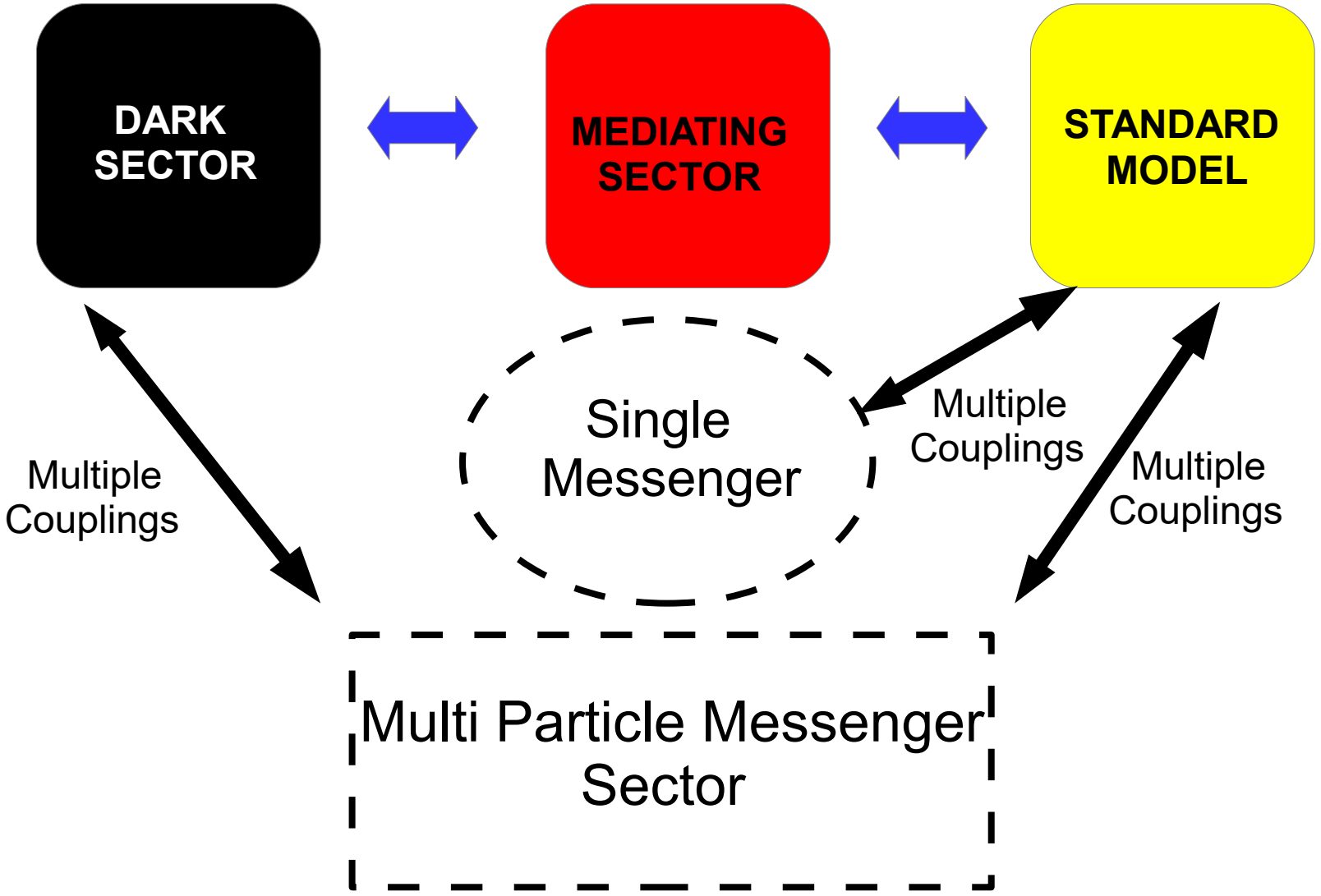


- Chooses a mediating mechanism
- Considers limited number of interactions
- Issue with arbitrarity and theoretical consistency (unitarity, gauge invariance)
- Not every simplified model can be realized in UV completion

Next Generation Models

- **Theoretically consistent** extension of a simplified model
- Generic enough to be used in the context of broader, more complete theoretical frameworks
- Varied phenomenology to encourage comparison of different experimental signals and to search for DM in new, unexplored channels
- Be of interest beyond the DM community, to the point that other direct and indirect constraints can be identified.

ArXiv:1810:09420


DARK SECTOR
MEDIATING SECTOR
STANDARD MODEL
Single Messenger
Multiple Couplings
Multiple Couplings
Multiple Couplings
Multi Particle Messenger Sector

Computing the Annihilation Spectrum

Partial Annihilation Rates

The total annihilation rate sums all channels

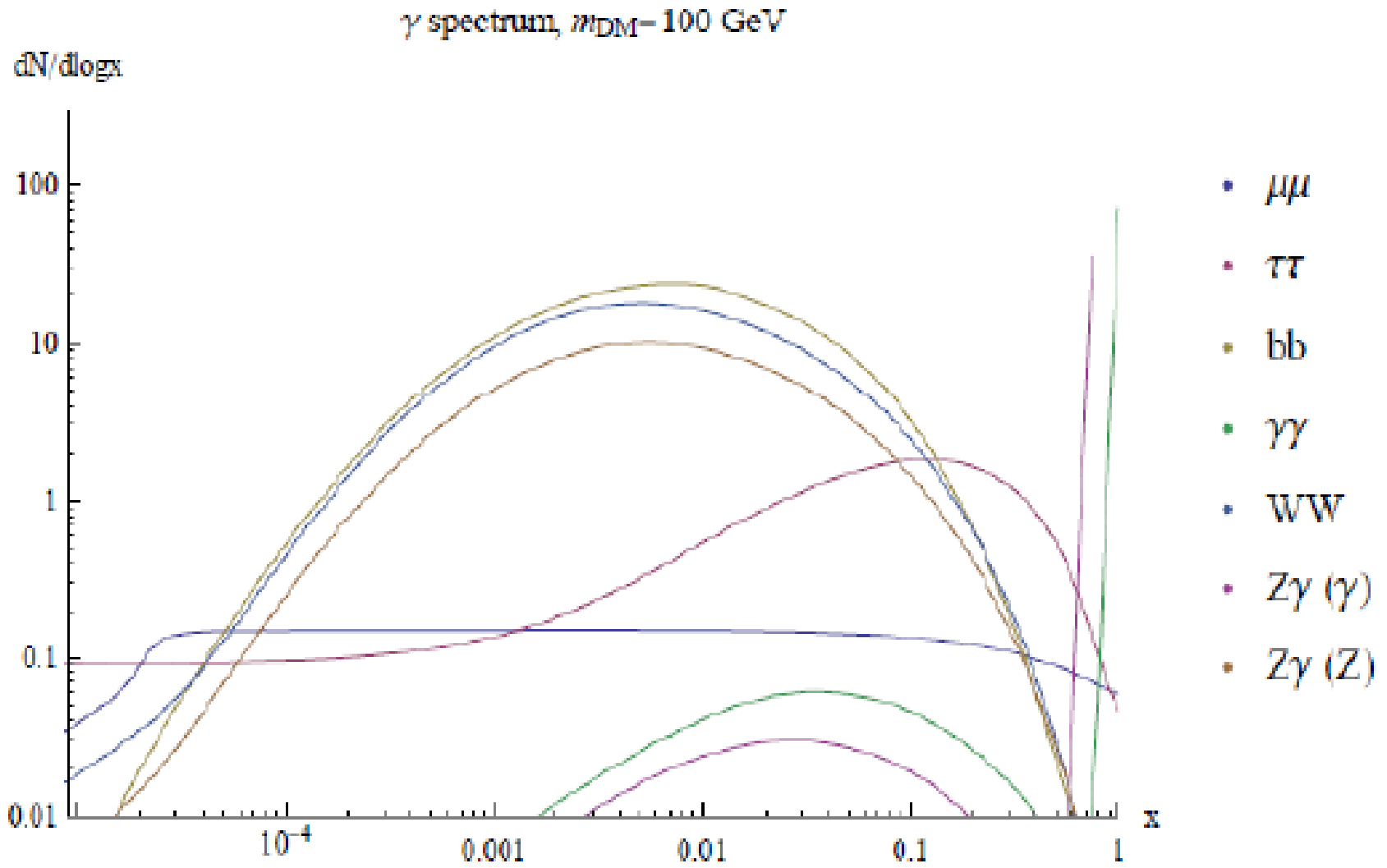
$$\Sigma \langle \sigma v \rangle_i = \langle \sigma v \rangle_{Total}$$

In analogy to branching fractions we define the partial rates R_i

$$R_i = \langle \sigma v \rangle_i / \langle \sigma v \rangle_{Total}$$

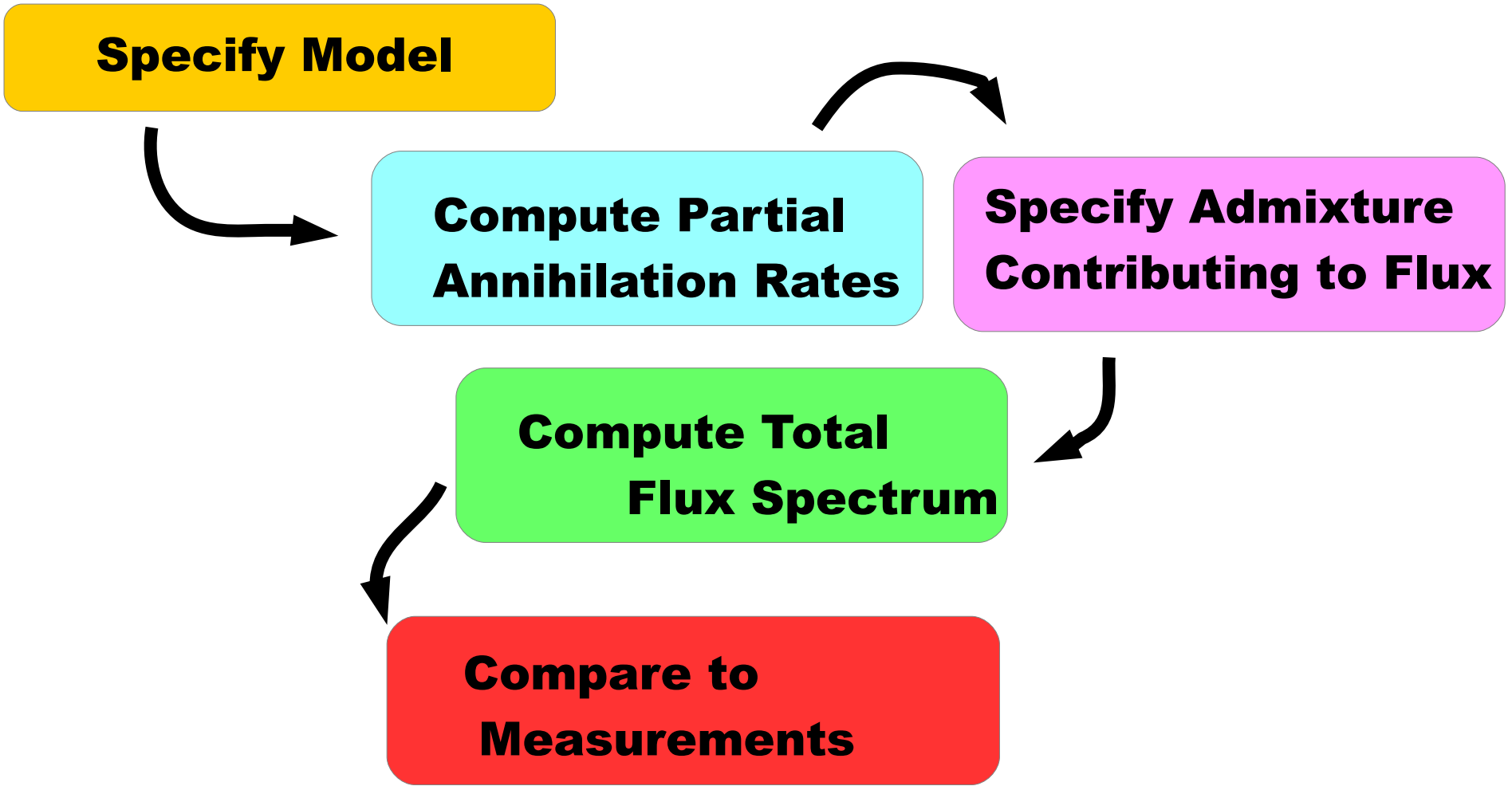
With the constraint

$$\Sigma R_i = 1$$



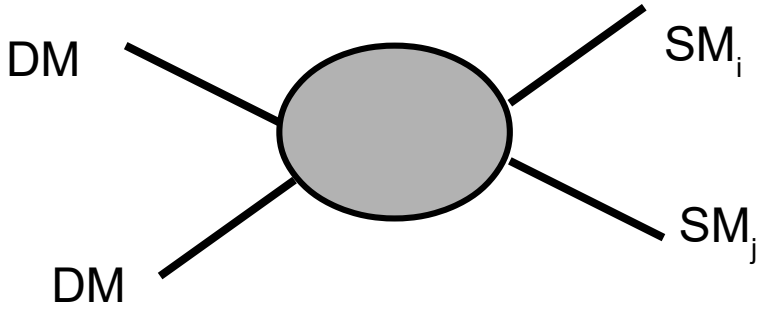
DM annihilates to various SM final states each with a characteristic photon spectrum

Calculation of Annihilation Spectrum



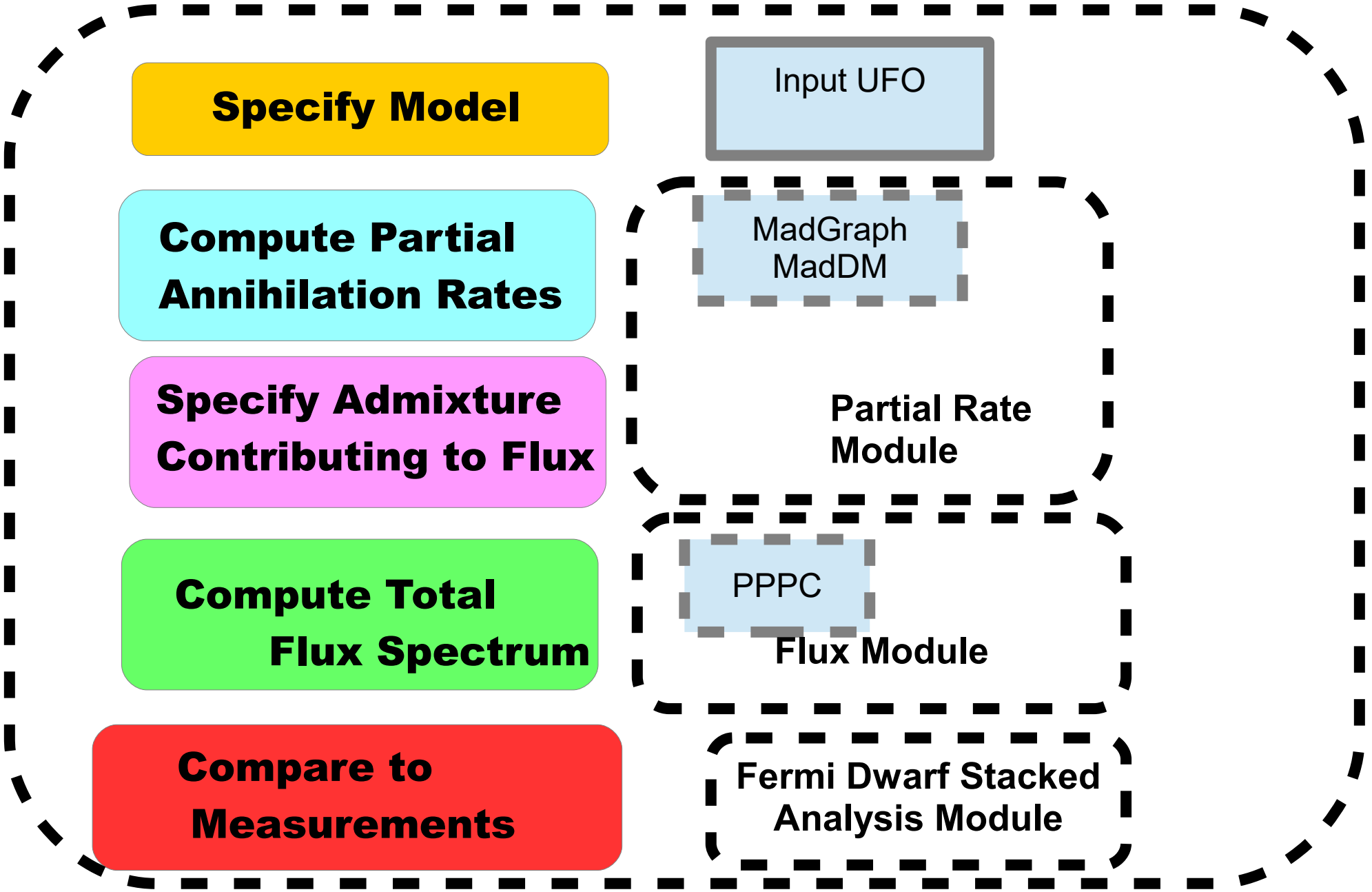
New Tool

- Input Model with 2-2 Topology
- Compute DM partial rates directly to SM pairs
- Outputs binned photon flux spectrum
- Compares to Fermi limits

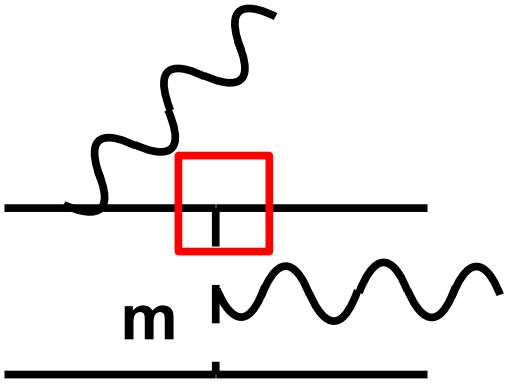


DM annihilates in 2-2 topology
DM is neutral

Automated Calculation

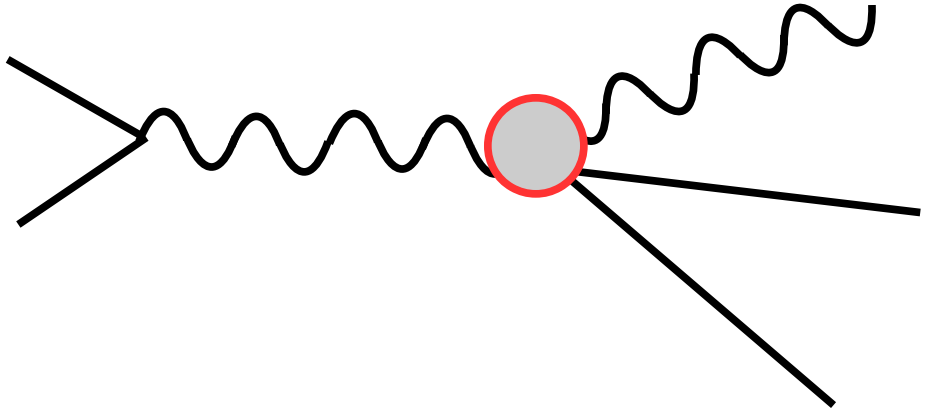


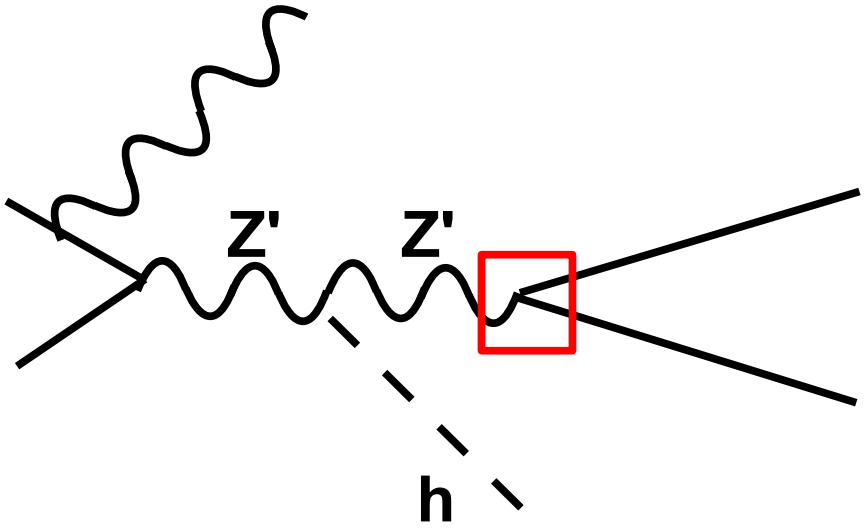
ILC Models



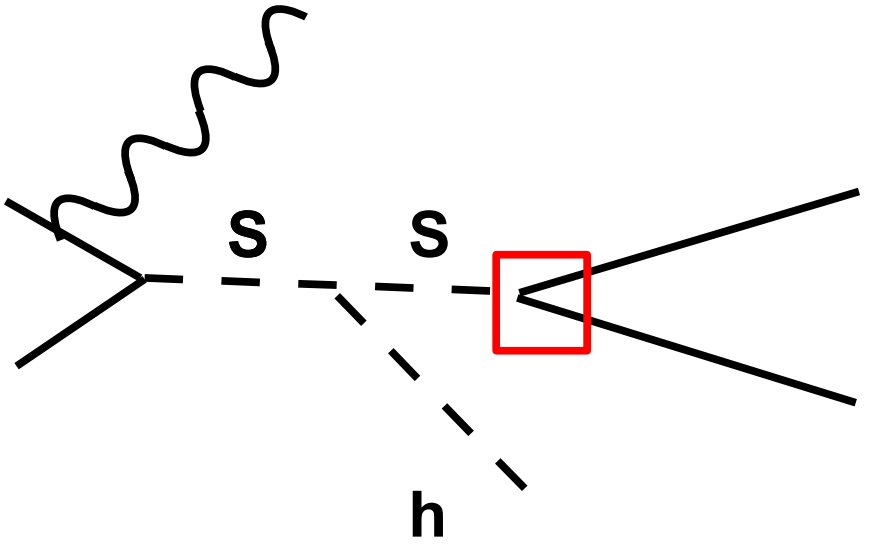
Scalar Mediator models

Gauge Boson portal models



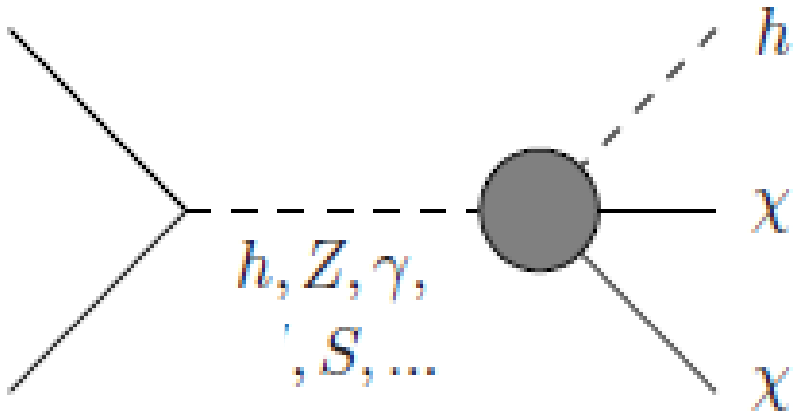


Z' models



Scalar /Higgs portal models

Mono Higgs Search



$$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi H^\dagger iD_\mu H\,, \quad \frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma_5\chi H^\dagger iD_\mu H$$

$$\frac{1}{\Lambda^4}\bar{\chi}\gamma^\mu\chi B_{\mu\nu}H^\dagger D^\nu H\,, \quad \frac{1}{\Lambda^4}\bar{\chi}\gamma^\mu\chi W^a_{\mu\nu}H^\dagger t^a D^\nu H$$

$$\frac{1}{\Lambda^4}\bar{\chi}\sigma^{\mu\nu}\chi B_{\mu\nu}H^\dagger H\,, \quad \frac{1}{\Lambda^4}\bar{\chi}\sigma^{\mu\nu}\chi W^a_{\mu\nu}H^\dagger t^a H$$

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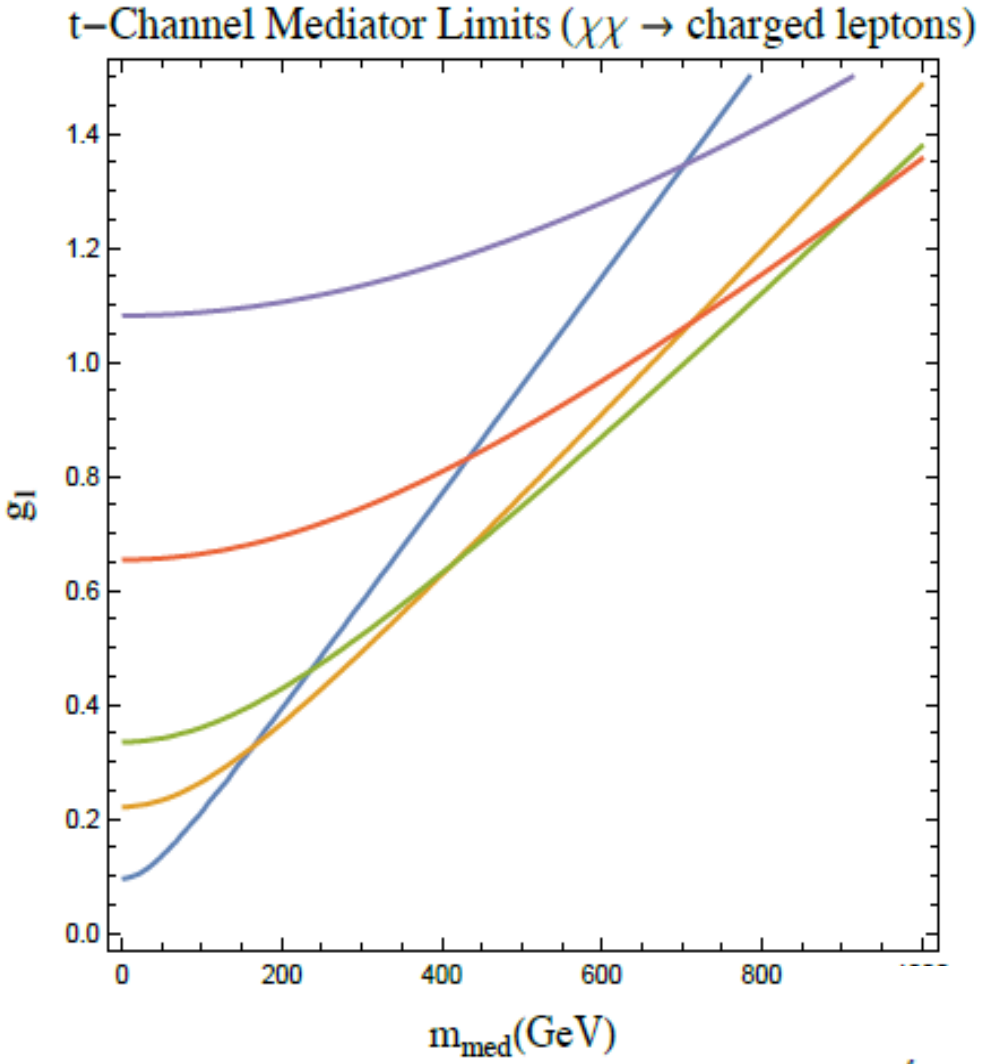
ID Constraints t channel mediator models



$$\mathcal{L} = \sum_i g_i \phi_i^* \bar{\chi} P_R f_i + h.c.,$$

$$\langle \sigma v \rangle (\bar{\chi}\chi \to f_i \bar{f}_i) = \frac{N_c^f g_i^4 m_\chi^2}{32\pi (M_i^2 + m_\chi^2)^2},$$

Pseudoscalar Mediator

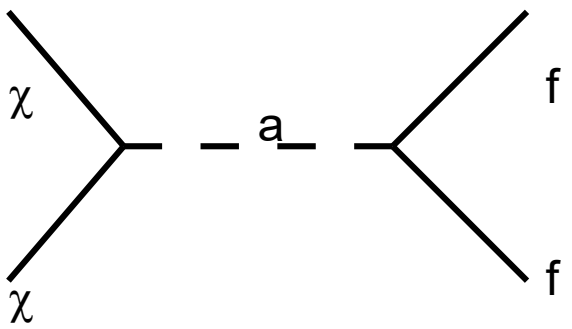
- EFT

$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q \qquad \bar{\chi}\chi\bar{q}q$ D1 and D3 operators

$$: \sum_{f=u,d,s,c,b,t,e,\mu,\tau} \left(\frac{C_1^f}{\Lambda^2}\bar{f}f\bar{\chi}\chi + \frac{C_2^f}{\Lambda^2}\bar{f}\gamma_5 f\bar{\chi}\gamma_5\chi + \ldots \right)$$

- Simplified Model

$$\mathcal{L}_{\text{DM-simp}} = -ig_\chi a\bar{\chi}\gamma_5\chi - ia\sum_j \left(g_u y_j^u \bar{u}_j\gamma_5 u_j + g_d y_j^d \bar{d}_j\gamma_5 d_j + g_\ell y_j^\ell \bar{\ell}_j\gamma_5\ell_j \right)$$



Violates gauge invariance!

Next Gen Model 2HDM+P

H, h, H^{+-}, A, a

DM coupling to pseudoscalar

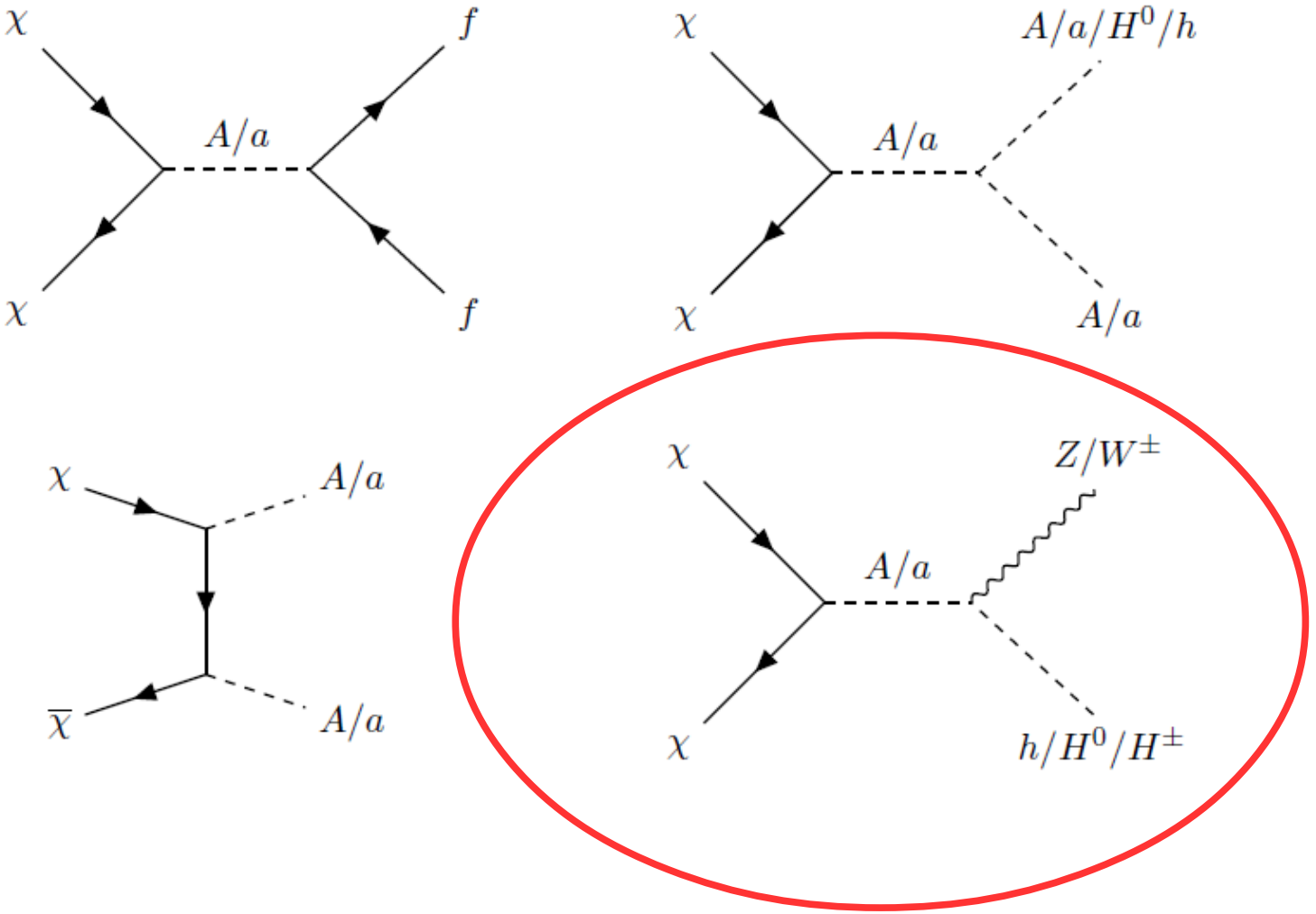
$$\mathcal{L}_\chi = -iy_\chi P \bar{\chi} \gamma_5 \chi$$

Pseudoscalar mixing with SM

$$V_{HP} = P\left(ib_P H_1^\dagger H_2 + \text{h.c.}\right) + P^2\left(\lambda_{P1} H_1^\dagger H_1 + \lambda_{P2} H_2^\dagger H_2\right)$$

Higgs coupling to SM

$$\mathcal{L}_Y = -\sum_{i=1,2}\left(\bar{Q} Y_u^i \tilde{H}_i u_R + \bar{Q} Y_d^i H_i d_R + \bar{L} Y_\ell^i H_i \ell_R + \text{h.c.}\right)$$

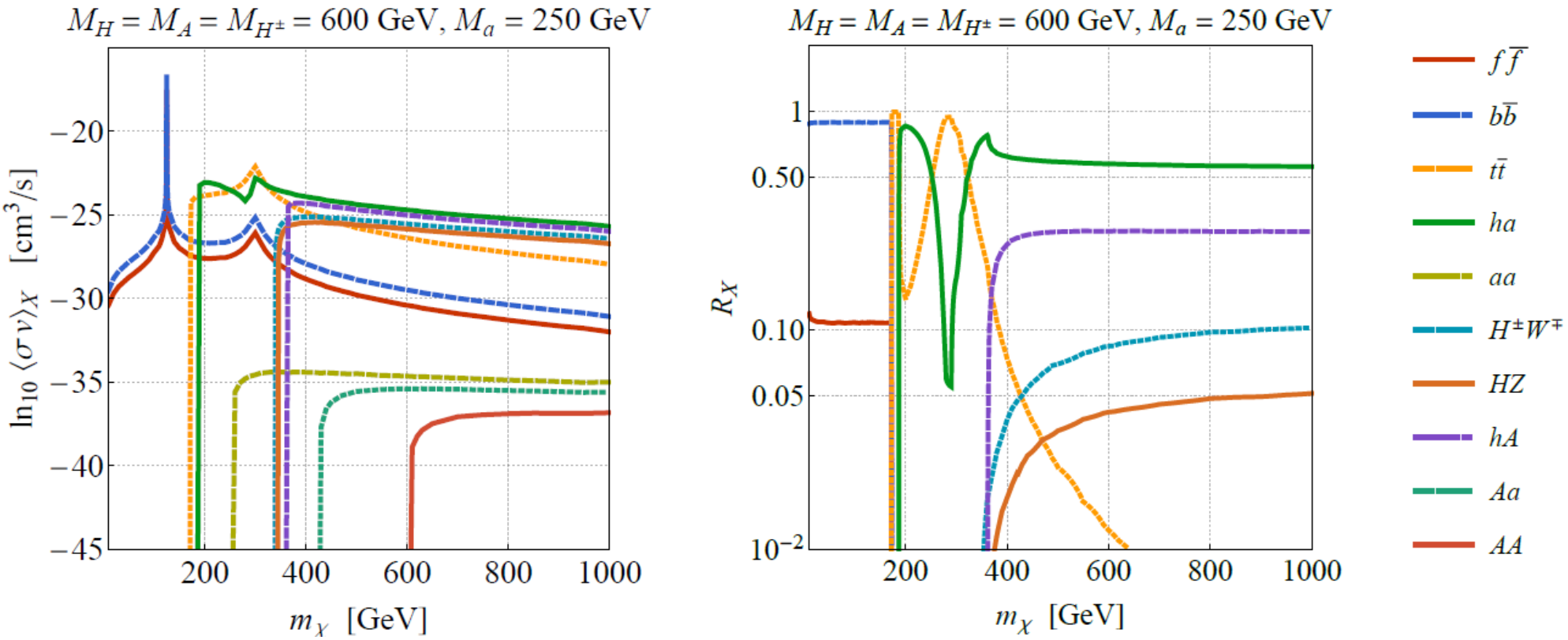


Mono Higgs Signature

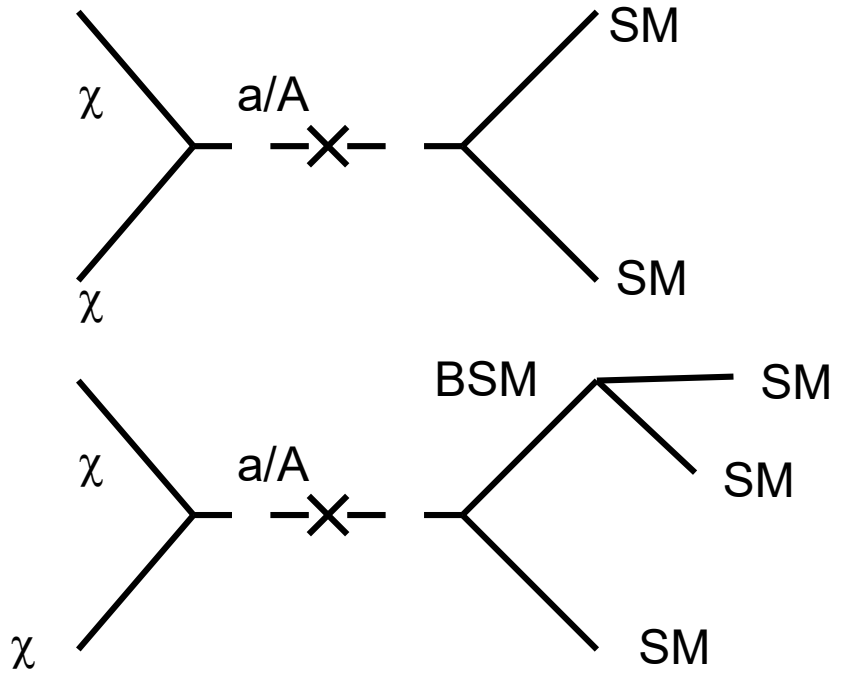
Indirect Detection Constraints

Dark Matter Annihilation channels through pseudoscalar

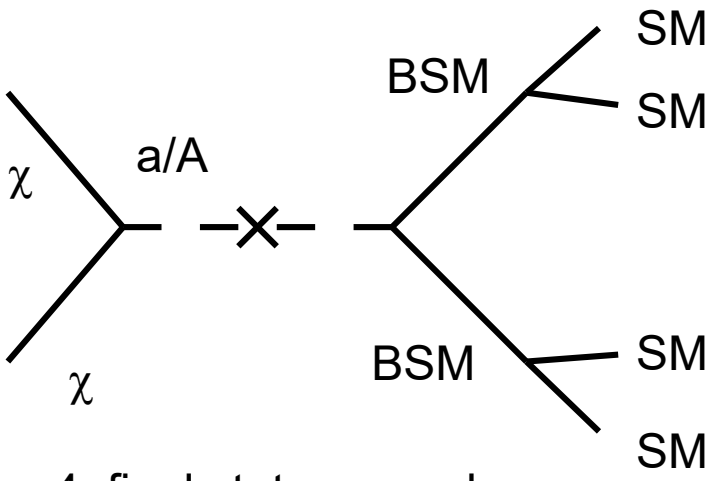
$$f\bar{f},\ hA,\ HA,\ HZ,\ H^{\pm}W^{\mp},\ ha,\ Ha,\ AA,\ aa \text{ and } Aa$$



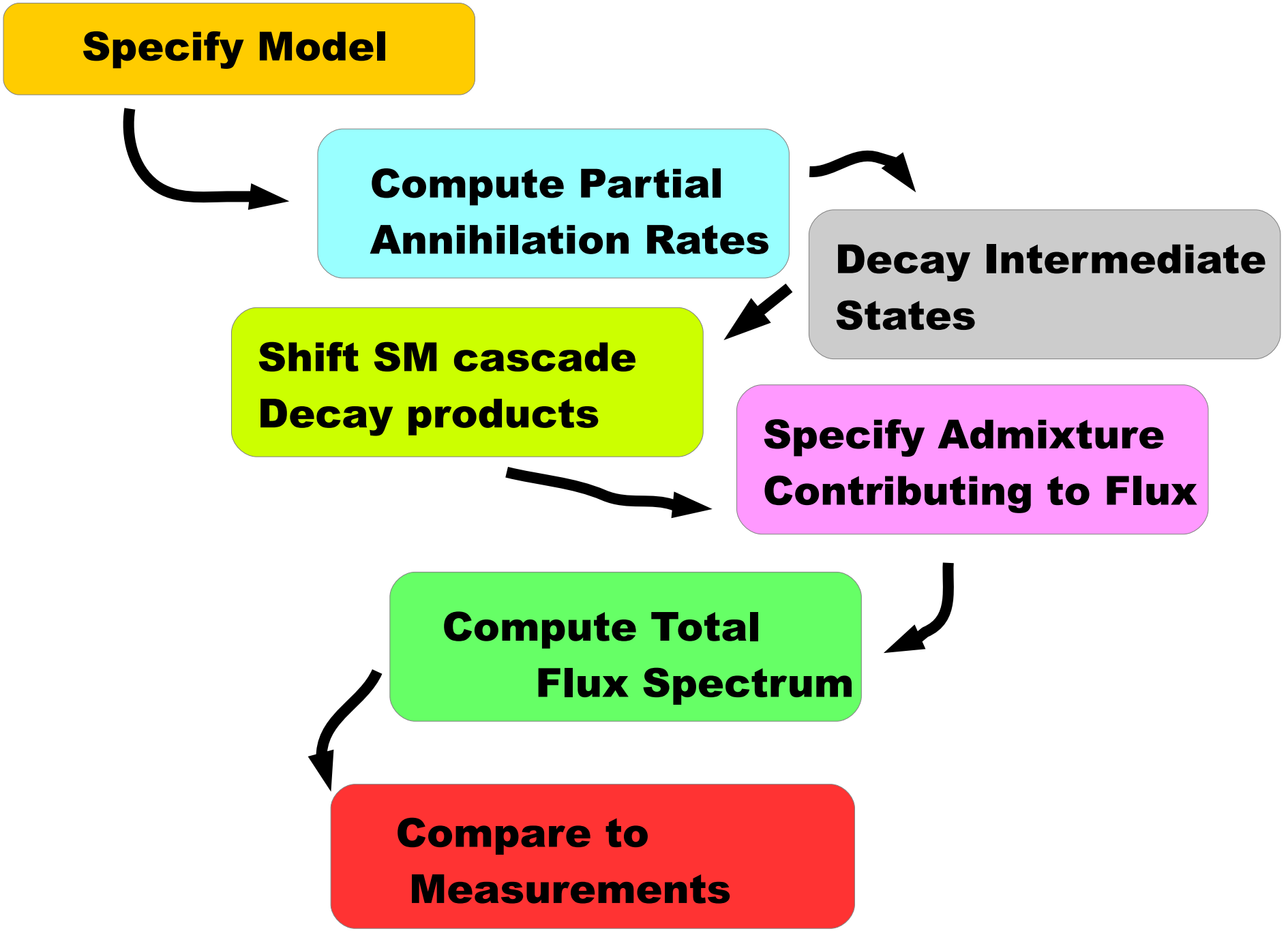
Next Steps Cascade Deays



3 final state cascade



4 final state cascade


Specify Model
Compute Partial Annihilation Rates
Decay Intermediate States
Shift SM cascade Decay products
Specify Admixture Contributing to Flux
Compute Total Flux Spectrum
Compare to Measurements

Conclusions

Automated Computation of ID spectrum

Handles Next Generation Models which require more complexity in the mediator sector

Great multiplicity of DM couplings to SM particles

DM annihilation process becomes complex, multiple final states and cascade decays

Complimentarity to collider searches

Multiple Next Gen portal Models with Higgs/Scalar and electroweak couplings both new complex ID spectra and ILC signatures