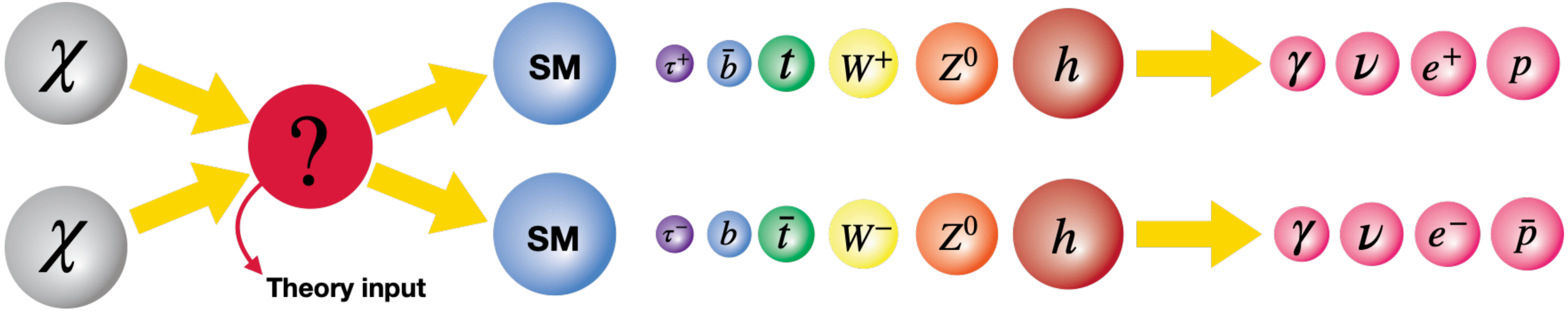
Charon: A Tool for Neutrino Flux Generation from WIMPs

Jeffrey Lazar on behalf of Q. Liu,
C. A. Argüelles, and A. Kheirandish

Dark Ghosts Workshop
Granada, Spain
1 Apr., 2022

WIMPs' Astrophysical Signatures



- Look for stable SM byproducts of WIMP annihilation or decay
- Neutrinos can escape dense astrophysical environments
- Look towards places where WIMPs are expected to accumulate

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- Neutrinos can escape dense astrophysical environments
- Look towards places where WIMPs are expected to accumulate

So you wanna do an indirect detection search…

- IceCube
  - Sun - WimpSim, Earth - WimpSim, GC - PYTHIA, DM decay - PPPC, IC+ANTARES combined PPPC
- Super-K
  - Sun- WimpSim, GC - DarkSUSY
- ANTARES
  - Sun - WimpSim, Earth - WimpSim, GC - PPPC

Neutrinos from WIMP Annihilations Obtained Using a Full Three-Flavor Monte Carlo Approach

Mattias Blennow,[1,*] Joakim Edsjö,[2,†] and Tommy Ohlsson[1,‡]

PPPC 4 DM ID:
A Poor Particle Physicist Cookbook for Dark Matter Indirect Detection

Marco Cirelli[a,b], Gennaro Corcella[c,d,e], Andi Hektor[f], Gert Hütsi[g], Mario Kadastik[f], Paolo Panci[a,h,i,j], Martti Raidal[f], Filippo Sala[d,e], Alessandro Strumia[a,e,f,k]

So you wanna do an indirect detection search…

- Monte Carlo approach
  - Restricted to supported models
  - Hard-coded cross sections
  - Need to produce a lot of simulation to fill tails of distribution

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So you wanna do an indirect detection search…

- Precomputed tables with interpolation functions
  - All stable SM particles available for a number of common source
  - You get what you get: no custom fluxes, cross sections, new source, etc.…

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So you wanna do an indirect detection search…

- Monte Carlo simulator of hadronization, decays, interactions, etc
- Usually only used in vacuum-like environments

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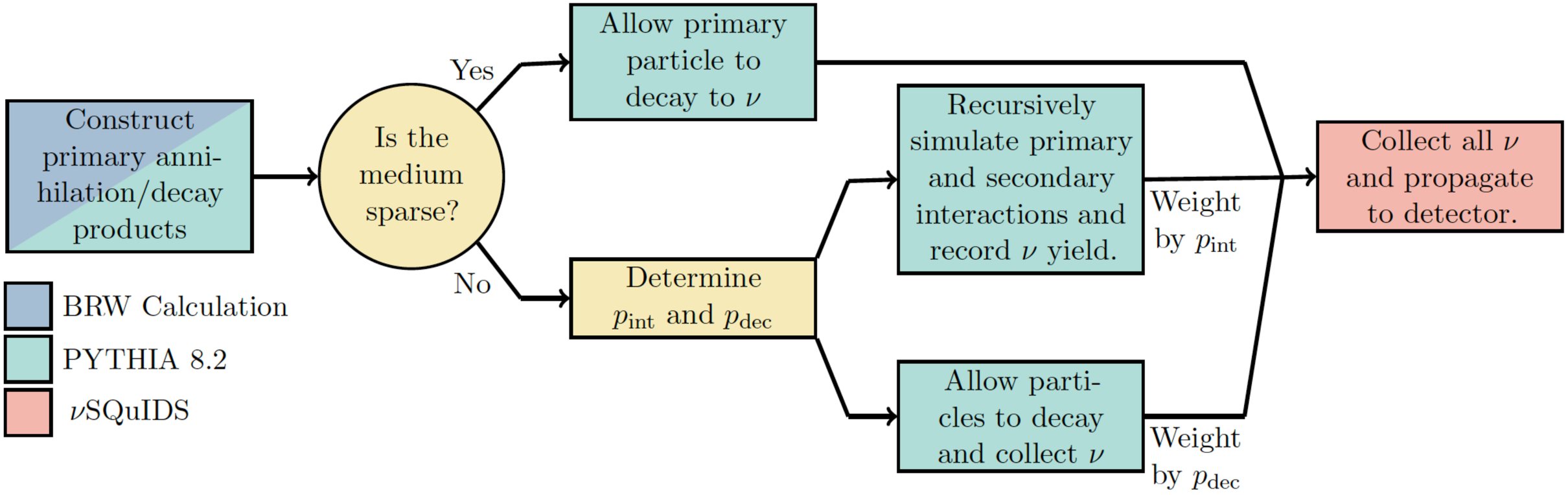
Motivation

- Vanilla WIMP scenario looking less likely
- More exotic BSM scenarios may modify the spectrum, cross sections, oscillation parameters, etc.

https://github.com/IceCubeOpenSource/charon

$\chi\alpha\rho\omega\nu$

χaroν Monte Carlo



PYTHIA 8.2 $m_\chi < 500$ GeV
BRW EW correction
$m_\chi \geq 500$ GeV

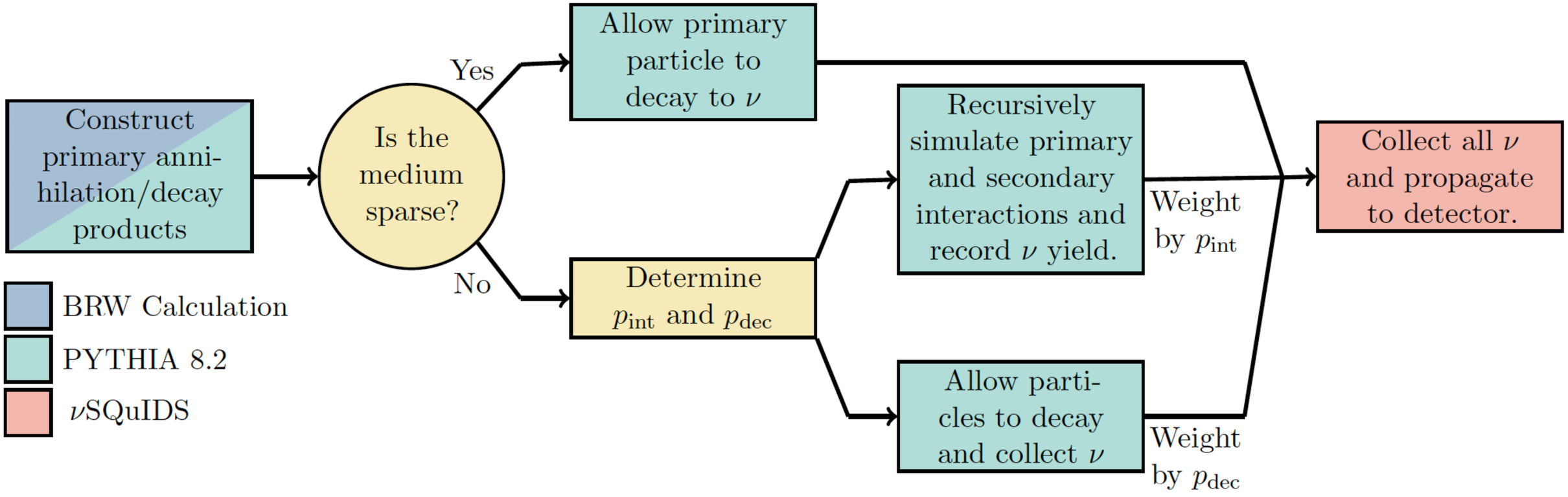
Dark Matter Spectra from the Electroweak to the Planck Scale

Christian W. Bauer,[1,2] Nicholas L. Rodd,[1,2] Bryan R. Webber[3]

An Introduction to PYTHIA 8.2

Torbjörn Sjöstrand[a,*], Stefan Ask[b,1], Jesper R. Christiansen[a], Richard Corke[a,2], Nishita Desai[c], Philip Ilten[d], Stephen Mrenna[e], Stefan Prestel[f,g], Christine O. Rasmussen[a], Peter Z. Skands[h,i]

χaroν Monte Carlo



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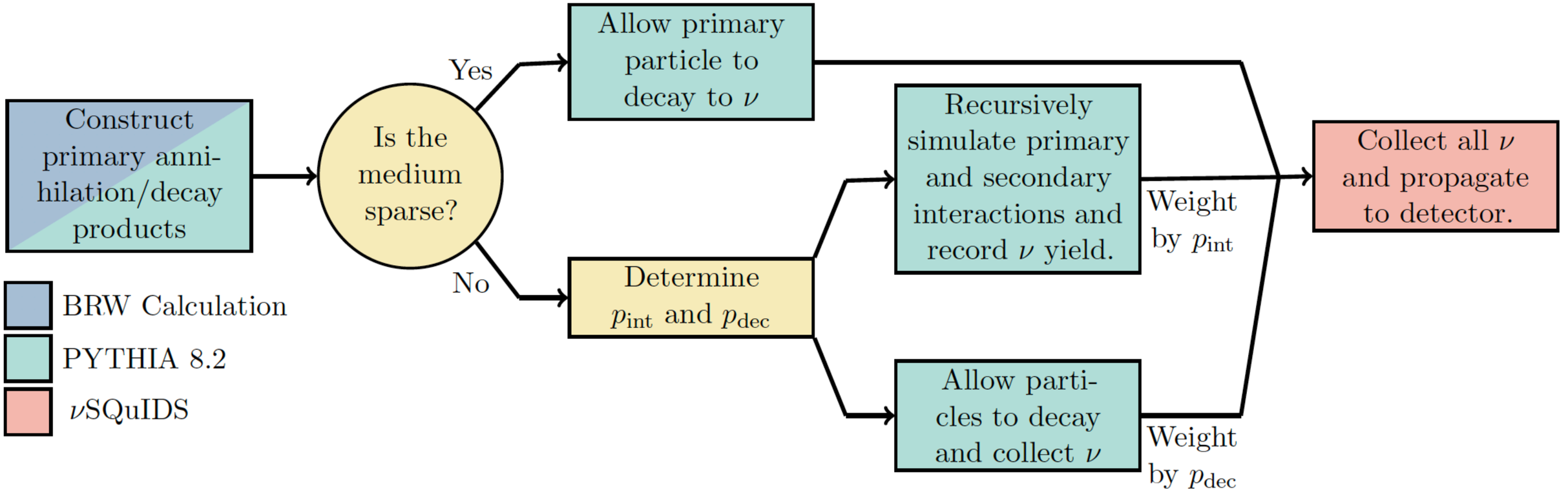
Internal χaroν MC

χaroν Monte Carlo



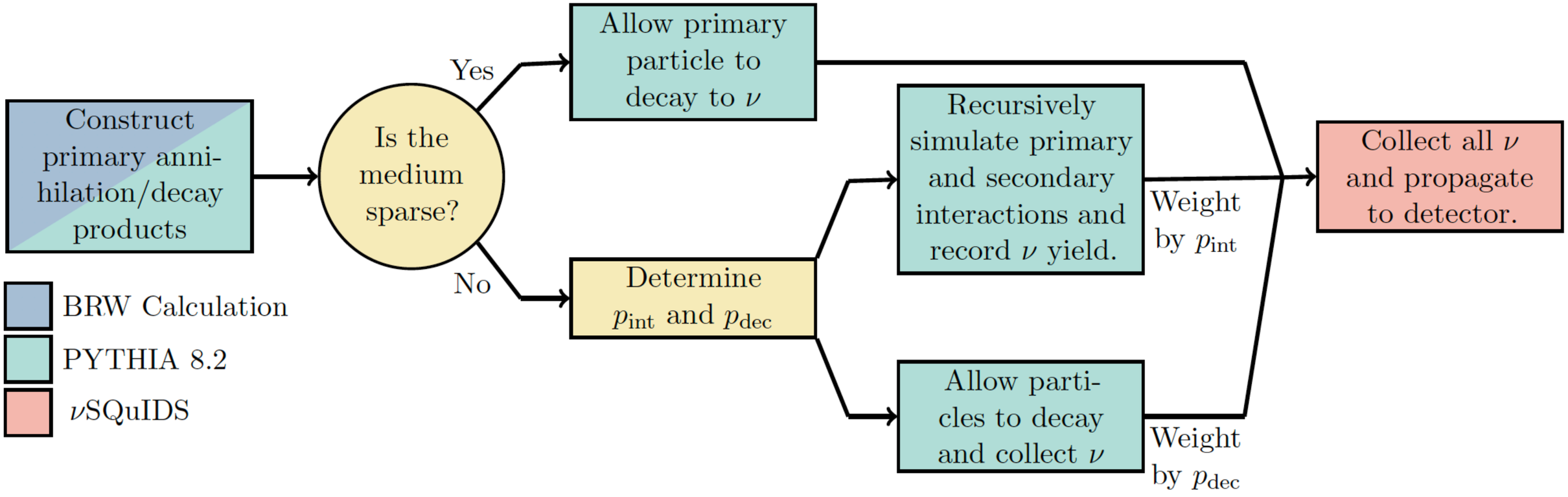
PYTHIA 8.2 $m_\chi < 500$ GeV
BRW EW correction
$m_\chi \geq 500$ GeV

nuSQuIDS: A toolbox for neutrino propagation*

Carlos A. Argüelles[a], Jordi Salvado[b], Christopher N. Weaver[c]

νSQuIDS

χaroν Monte Carlo



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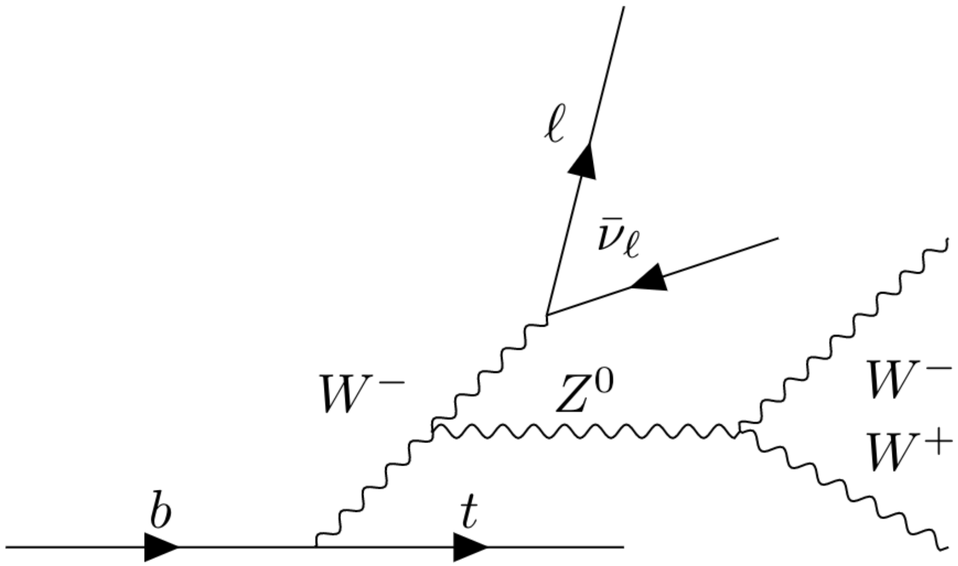
BRW EW correction
$m_\chi \geq 500$ GeV

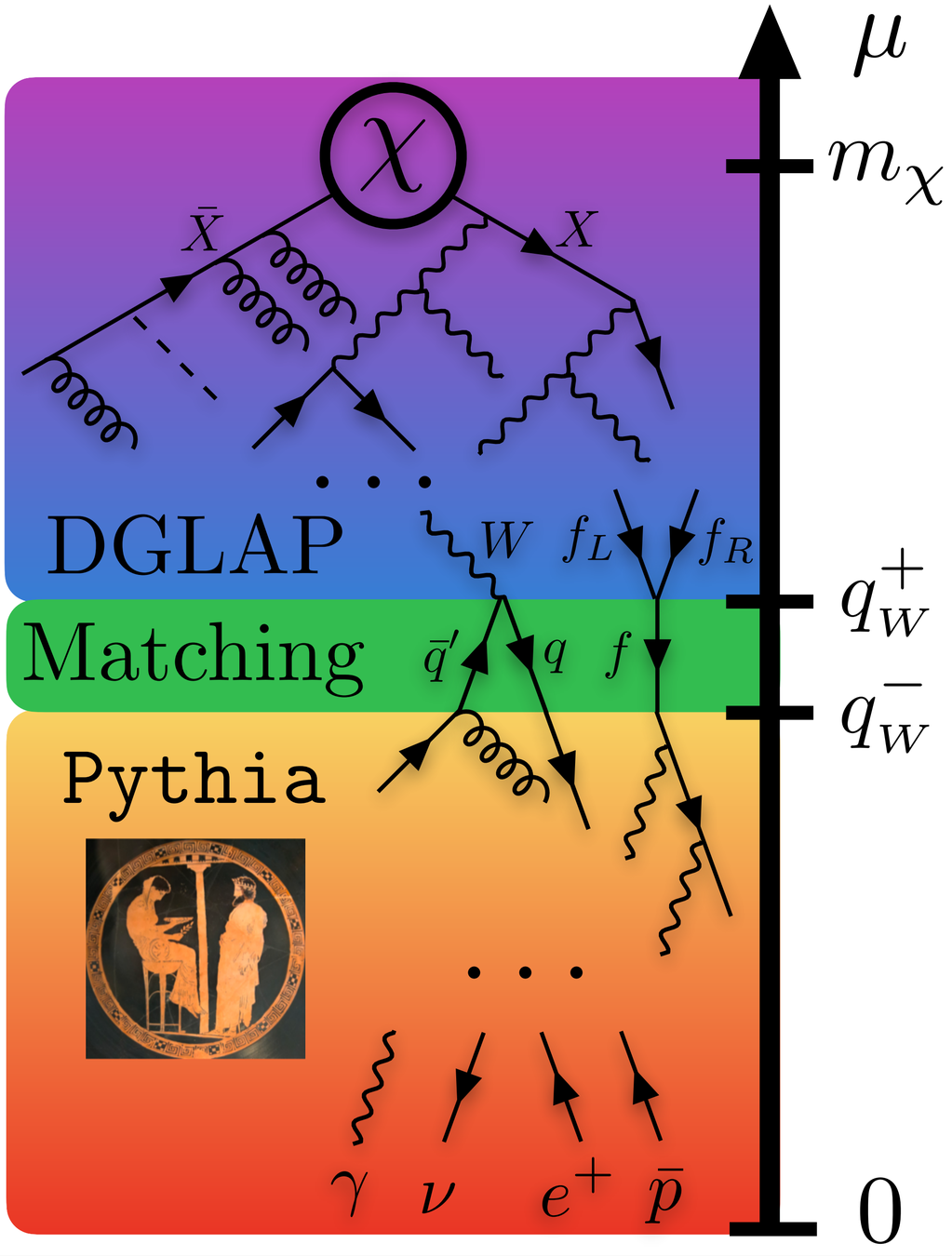
Internal χaroν MC

νSQuIDS

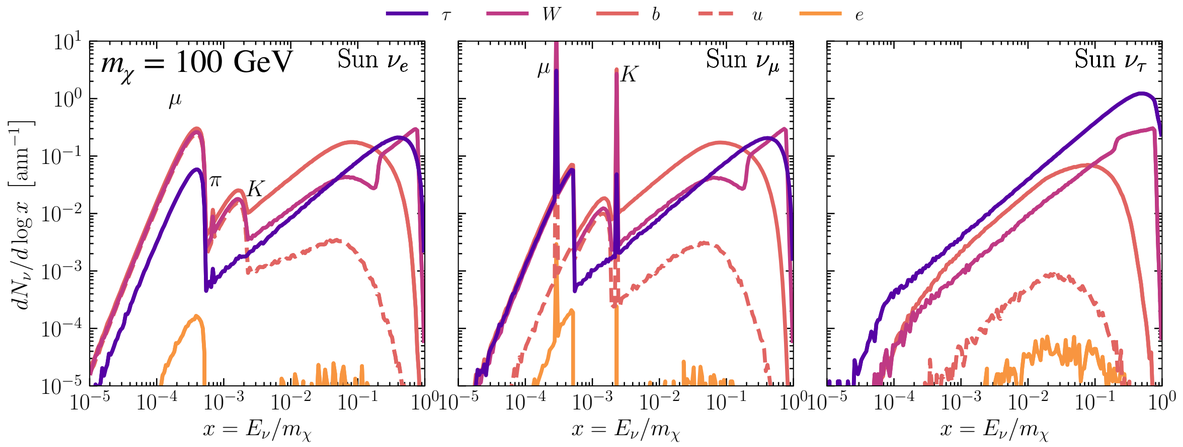
BRW Calculation

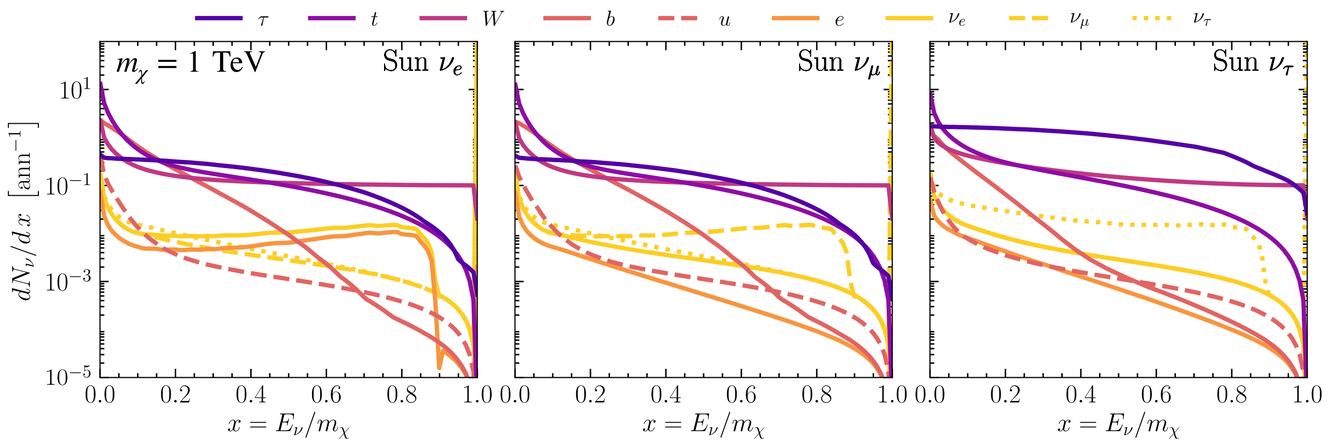
- Above electroweak scale— $\gtrsim 250$ GeV— $W^{\pm}$ and Z^0 can be radiated
- PYTHIA well-vetted below EW scale by collider data
- Evolve from DM scale down to EW scale+ϵ with DGLAP equations
- Matches calculation onto PYTHIA calculations





χaroν Production





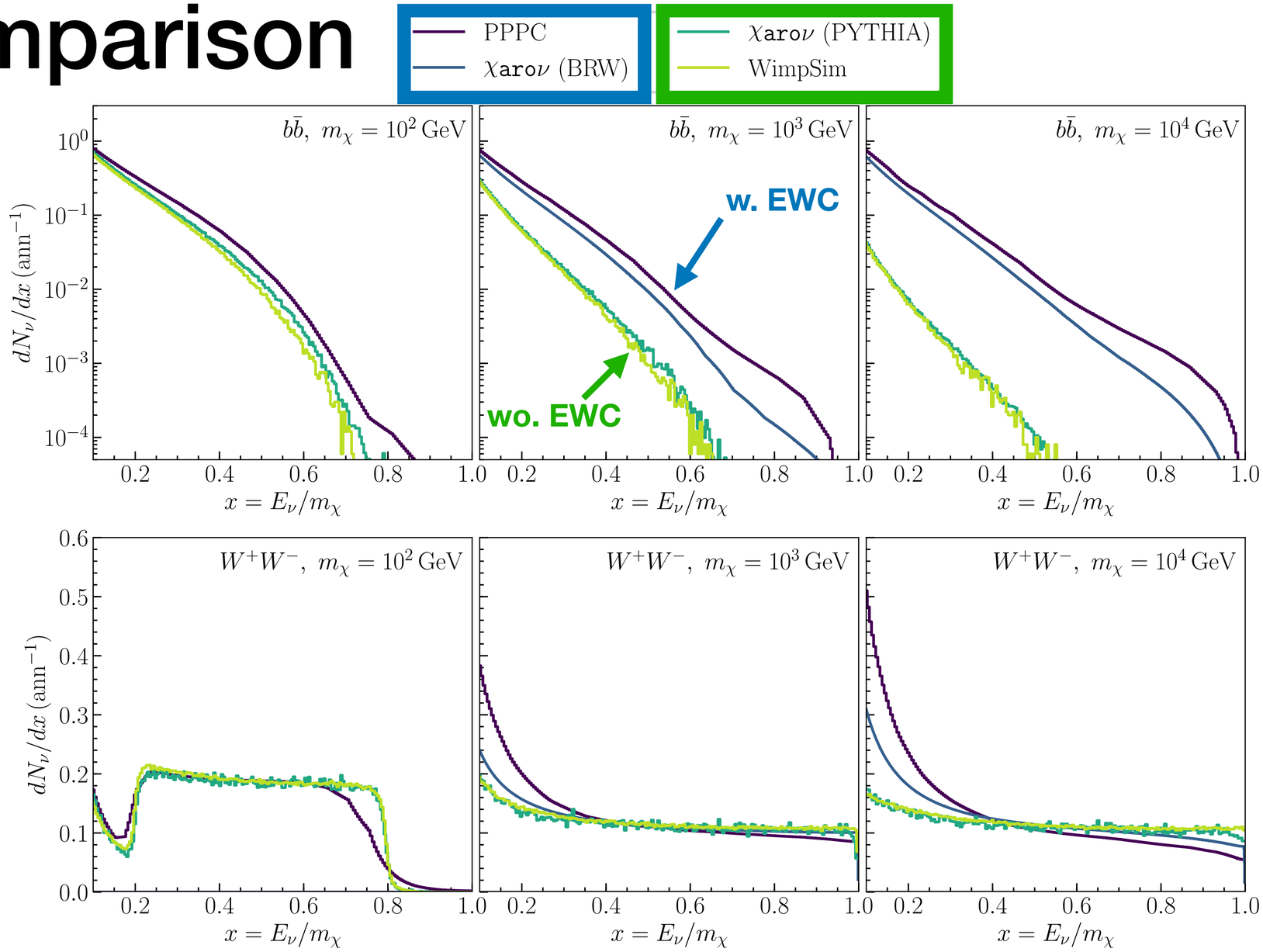
- Flavor-wise neutrinos at production for different annihilation channels for $m_\chi = 100$ GeV
- Option to include neutrinos from DAR turned on
- No electroweak correction

- Flavor-wise neutrinos at production for different annihilation channels for $m_\chi = 1$ TeV
- Option to include neutrinos from DAR turned off
- Electroweak correction turned on

We are happy to add a flux to the defaults if you like
Also support user input if you don't like our options !

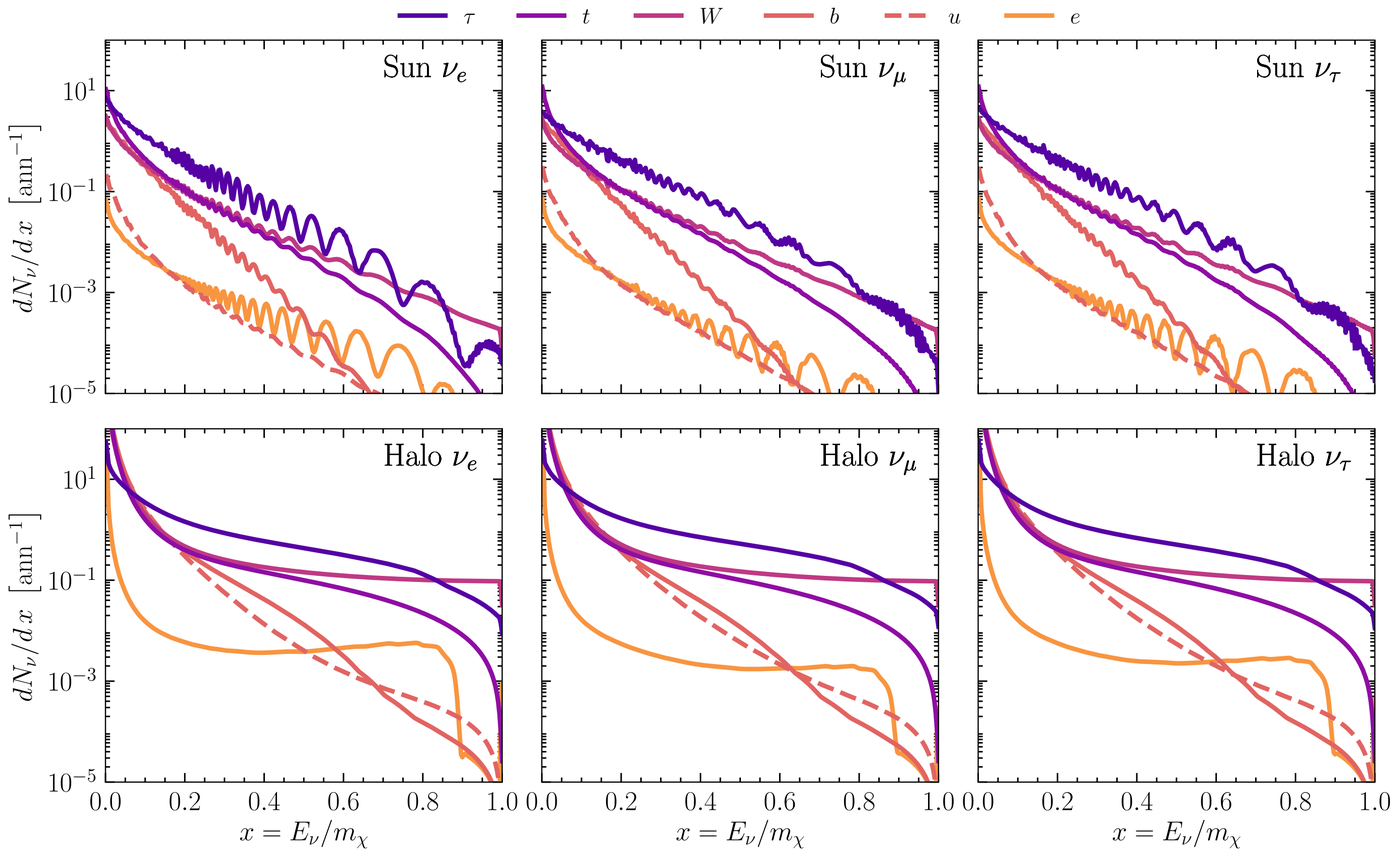
Production Comparison

- Order of magnitude changes in $b\bar{b}$ spectra; spectra harder
- Moderate changes in W^+W^- and $\tau^+\tau^-$ channels lead to softer spectra



χaroν Propagation

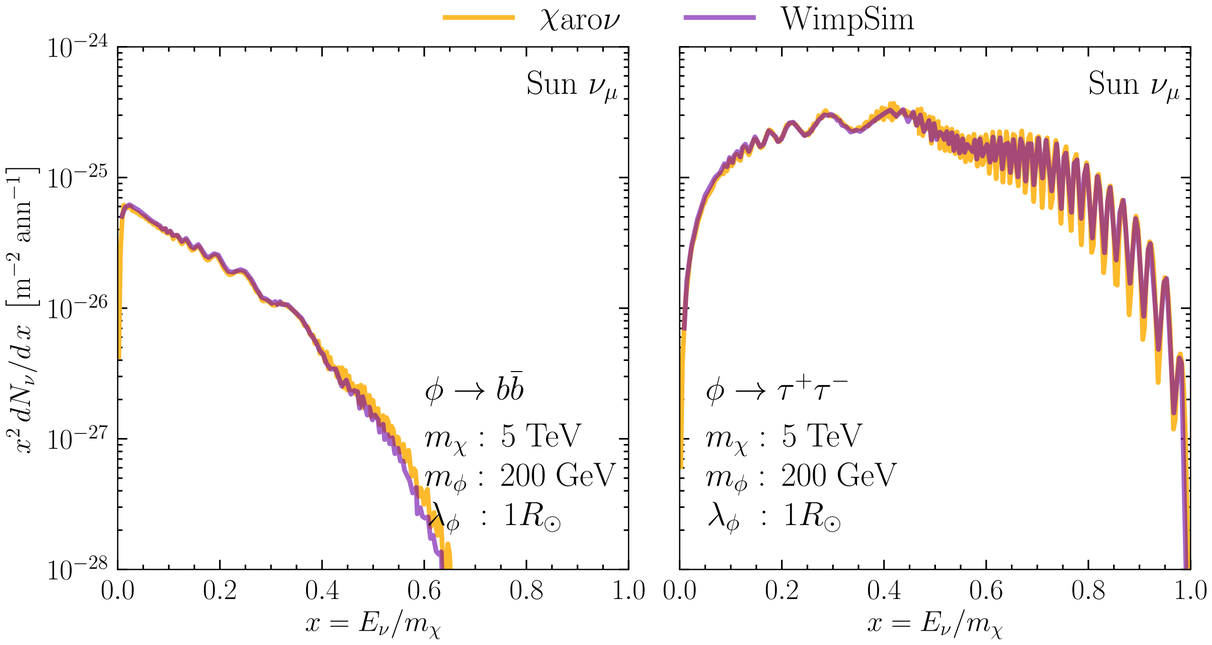
- νSQuIDS software allows easy modifications of prop. parameters, including:
  - Oscillation parameters (*NuFit 5.0*)
  - Cross sections (*nusigma* or Cooper-Sarkar)
  - Solar models (*struct_b16_agss09*, bs05_gsop, or struct_b16_gs98)
  - Earth models (*PREM*)

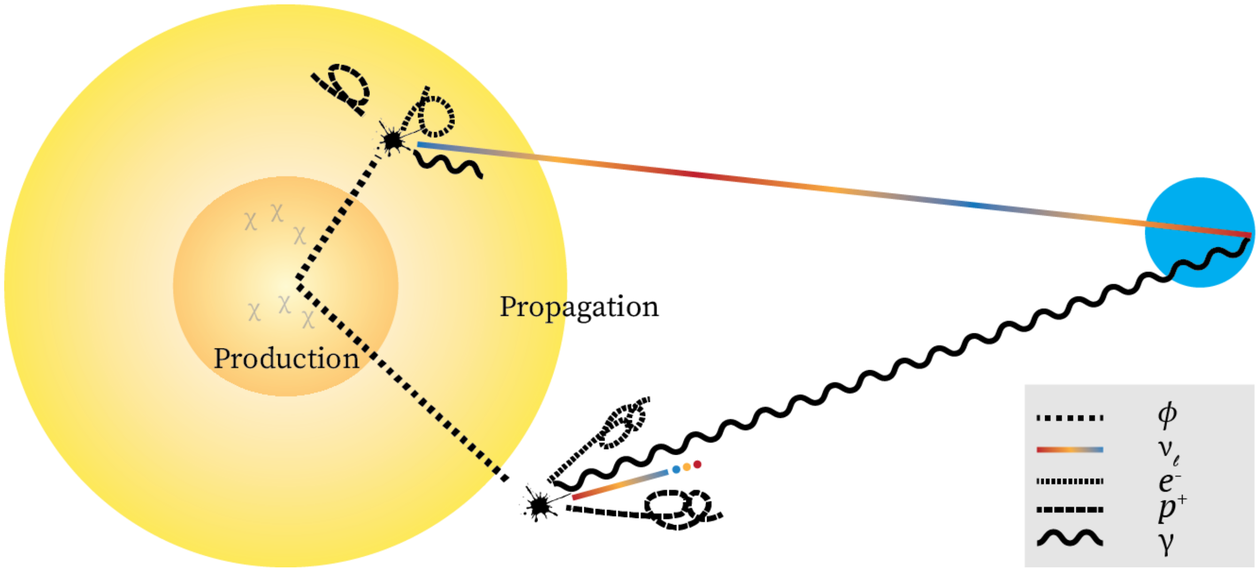


Once again user can provide their own !

Secluded Dark Matter

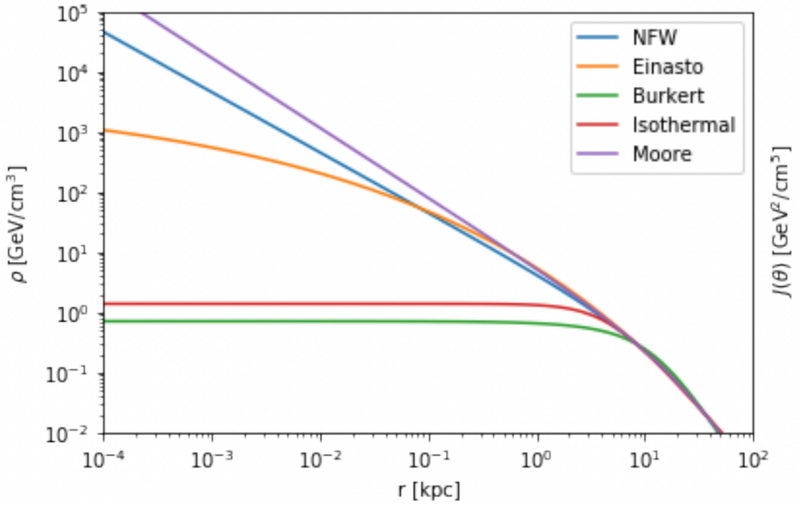
- Dark matter annihilates to meta-stable mediator, which decays to SM particles
- Electroweak correction not available. Working on implementing it

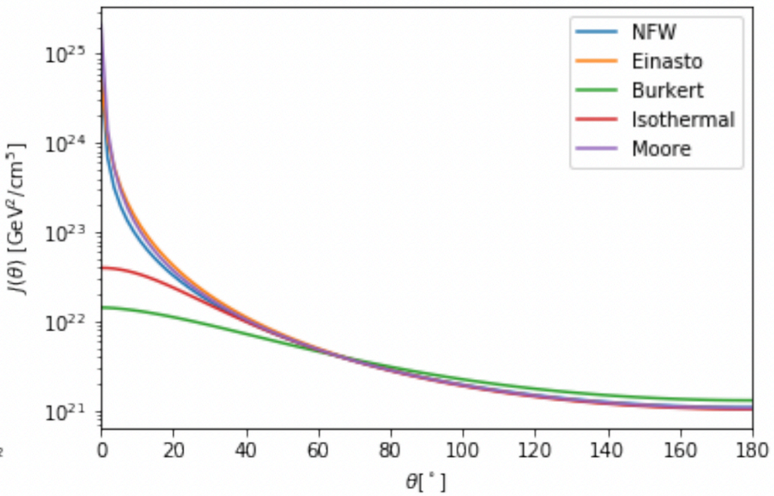


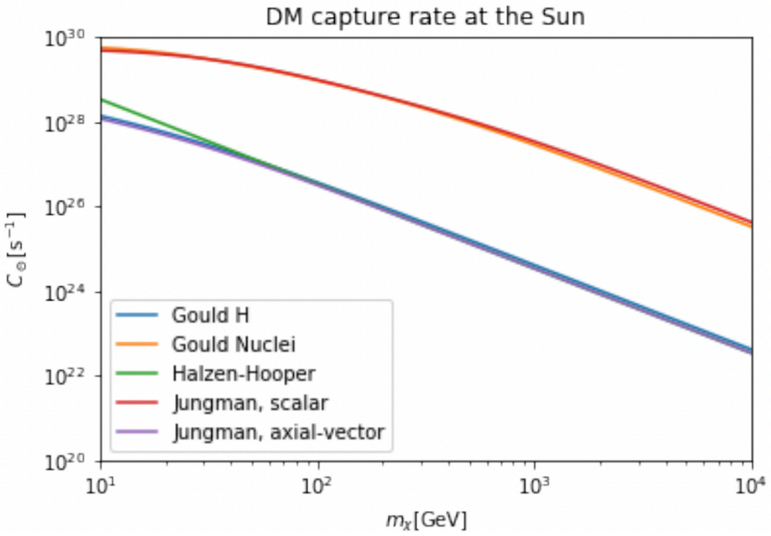


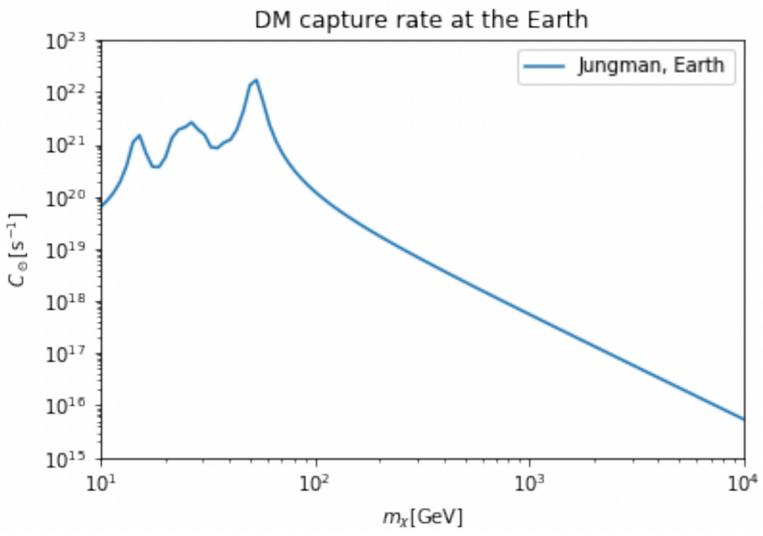
Other Features

- **Compute J factor**
  - Several typical profiles included - NFW, Einasto, Burkert…
  - Custom profiles are supported.









- **Calculate capture rate in Sun and Earth**
  - Several calculations included.
  - Sun/Earth model can be replaced.

Comparison

	Generation	EW corrections	Secluded DM	Long-lived particle stopped decay	Locations	Flux production	Propagation
WimpSim	**PYTHIA 6.4**	✗	✓	✗	**Earth, Sun**	Read files or run Fortran scripts	Read files or run Fortran scripts with oscillation parameters
PPPC	**PYTHIA 8.1 (+ GEANT4)**	✓	✗	✓	**Galactic Halo, Sun**	Read table in Mathematica	Read table in Mathematica
Charon wo/ BRW	**PYTHIA 8.2**	✗	✓	✓	**Galactic Halo, Sun, Earth or custom environment**	Read table or run C++ script	Flexible propagation with nuSQuIDs by allowing
Charon w/ BRW	**DGLAP + PYTHIA 8.2**	✓	✗ **(Yet)**	✗	**Galactic Halo, Sun, Earth**	Read table	options of input fluxes, oscillation parameters, xsec…

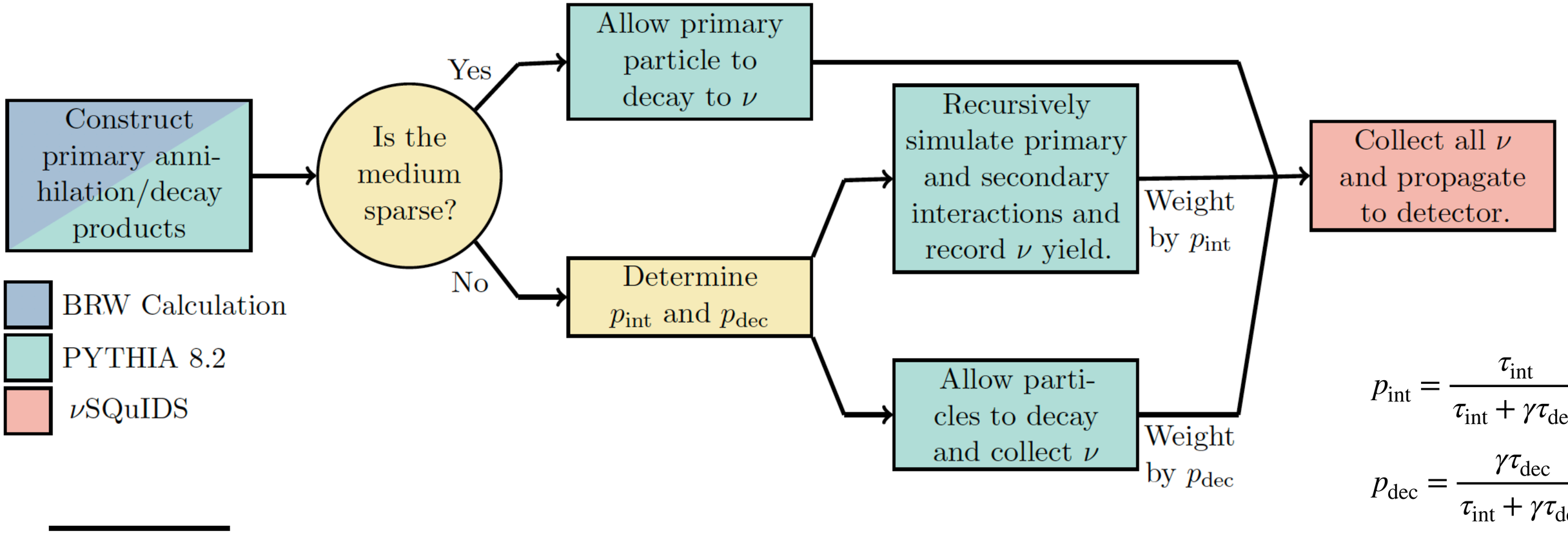
Conclusions

- χaroν is a flexible, Python-based package for speculating neutrinos form DM annihilation and decay
- Can be extended to new BSM scenarios easily
- Coupled to electroweak correction which can drastically change spectra, agrees with previous calculations when EWC turned off
- Many options currently supported, and almost all settings may be modified by users


Thank
You
WIMP
WIMP
WIMP
WIMP
WIMP

Backups

χaroν Monte Carlo



$$p_{\text{int}} = \frac{\tau_{\text{int}}}{\tau_{\text{int}} + \gamma\tau_{\text{dec}}}$$

$$p_{\text{dec}} = \frac{\gamma\tau_{\text{dec}}}{\tau_{\text{int}} + \gamma\tau_{\text{dec}}}$$