



Universidad
Zaragoza

WIMP reach of CYGNUS

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Outline

- **Impact of readout performance**
- **Subtracting the neutrino background**
- **Final reach plots**
- **(extra slides) WIMP astrophysics**

For reference: what has been included in reach calculations

Targets: Helium+Fluorine

- Helium at 740 torr ($1000\text{m}^3 = 0.16$ tons)
- Fluorine (SF_6) at 20 torr ($1000\text{m}^3 = 0.16$ tons)
- Separate limits for He/F, assumes recoils can be told apart 100% accurately
- No sulphur recoils

Background: Neutrinos

- Solar neutrinos: ${}^8\text{B}$, hep, ${}^7\text{Be}$
- Non-solar neutrinos: atmospheric ν_e, ν_μ , diffuse supernova background
- Perfect ER/NR discrimination (no electron recoils used)

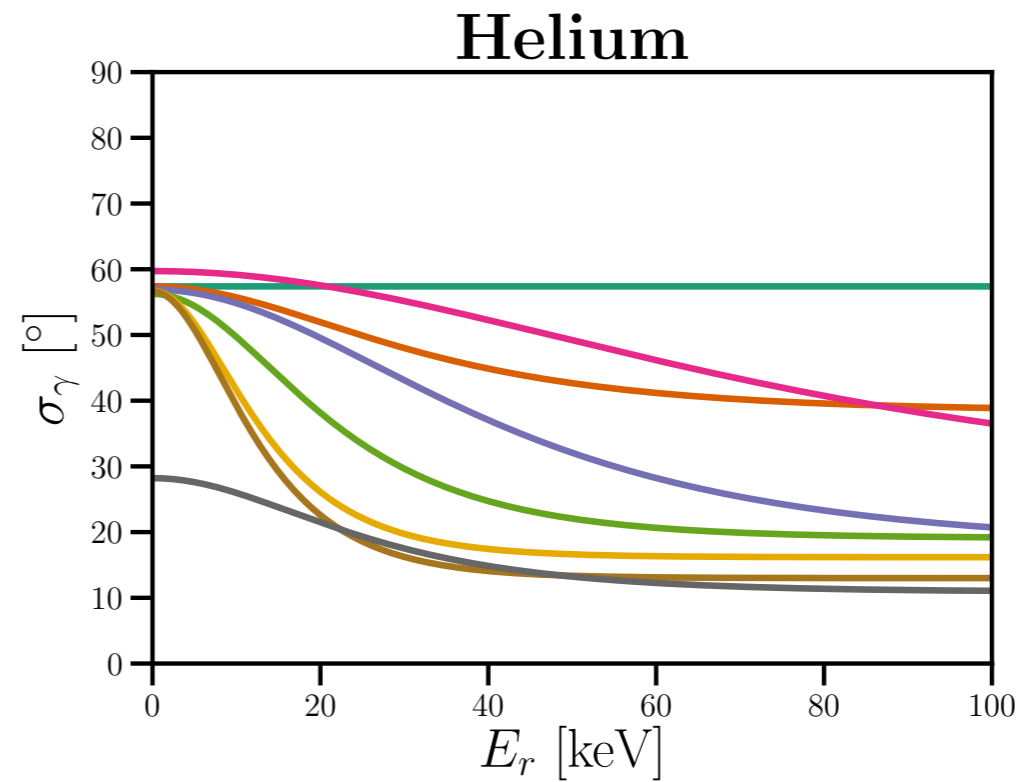
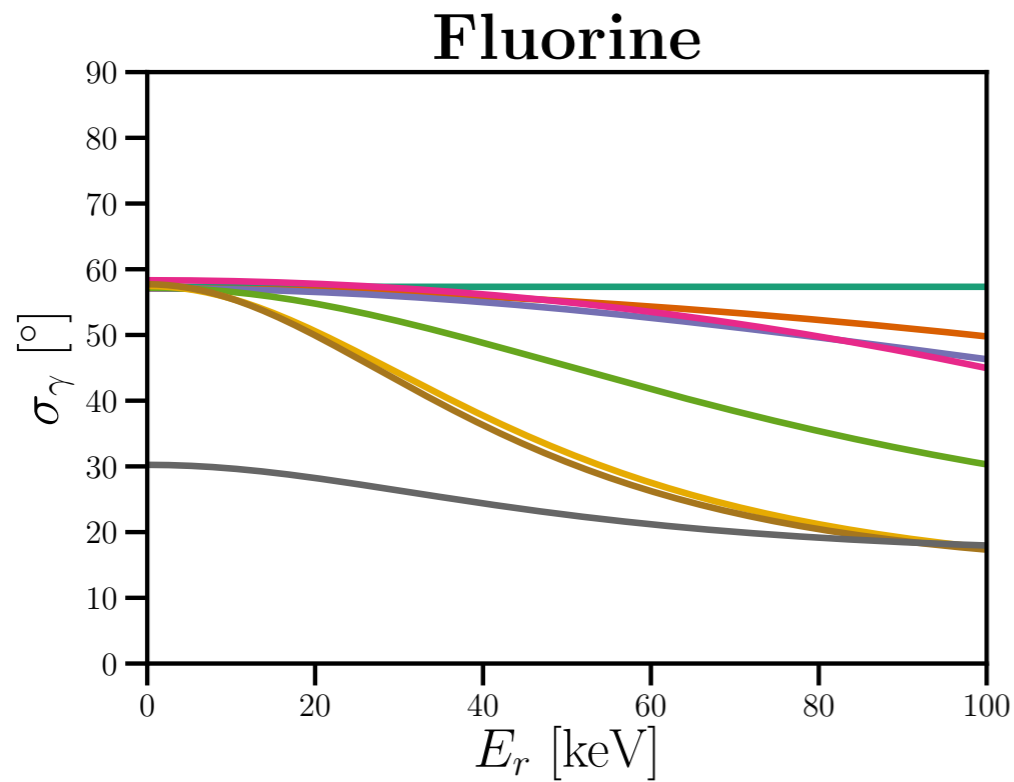
Detectors: $E > 1$ keVr (He) and $E > 3$ keVr (F)

Accounting for energy res, angular res, head-tail eff., charge detection eff.

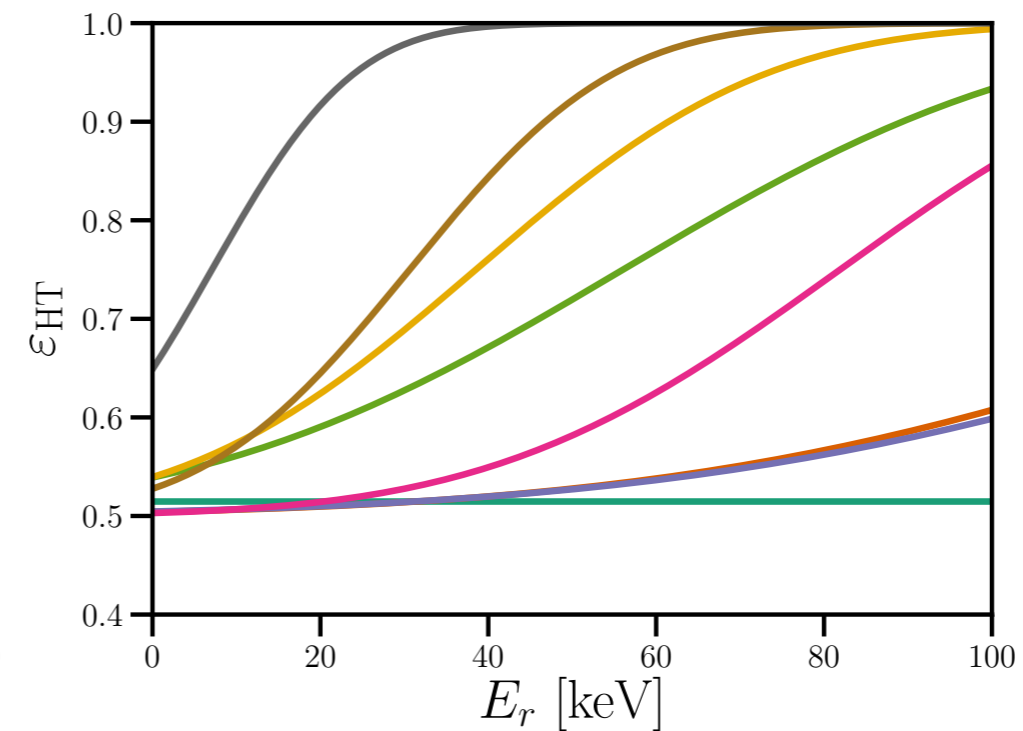
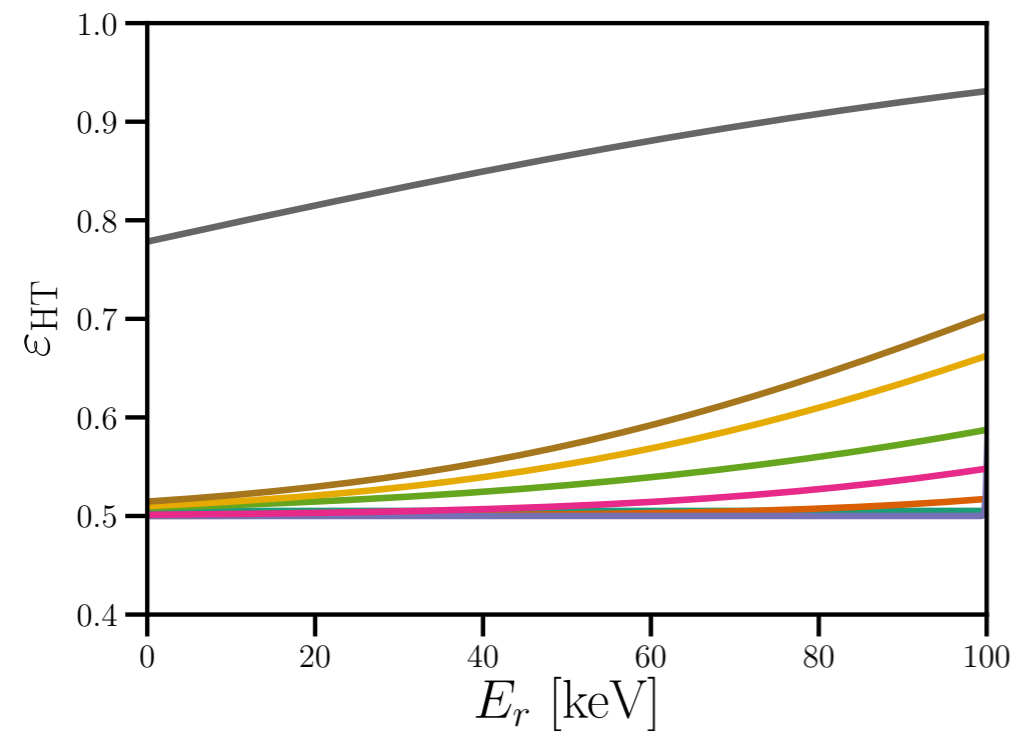
- Sven's = pixel (pre-drift+post-drift), strip, pad, planar, wire, optical
- + "Idealised" = directional with perfect detector performance
- + "Non-directional" = idealised, but throwing away directional info.

Readout performance

Angular resolution

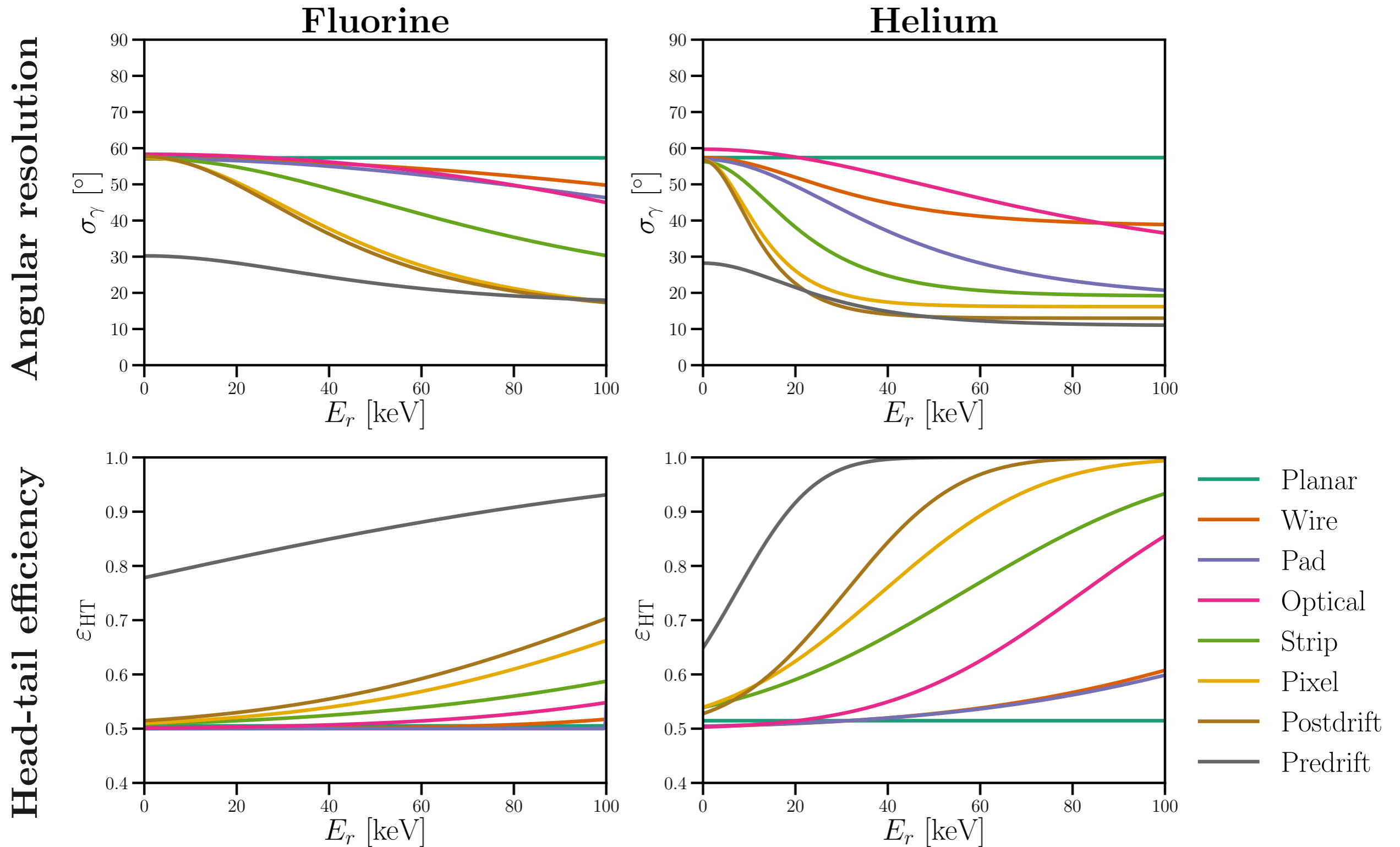


Head-tail efficiency

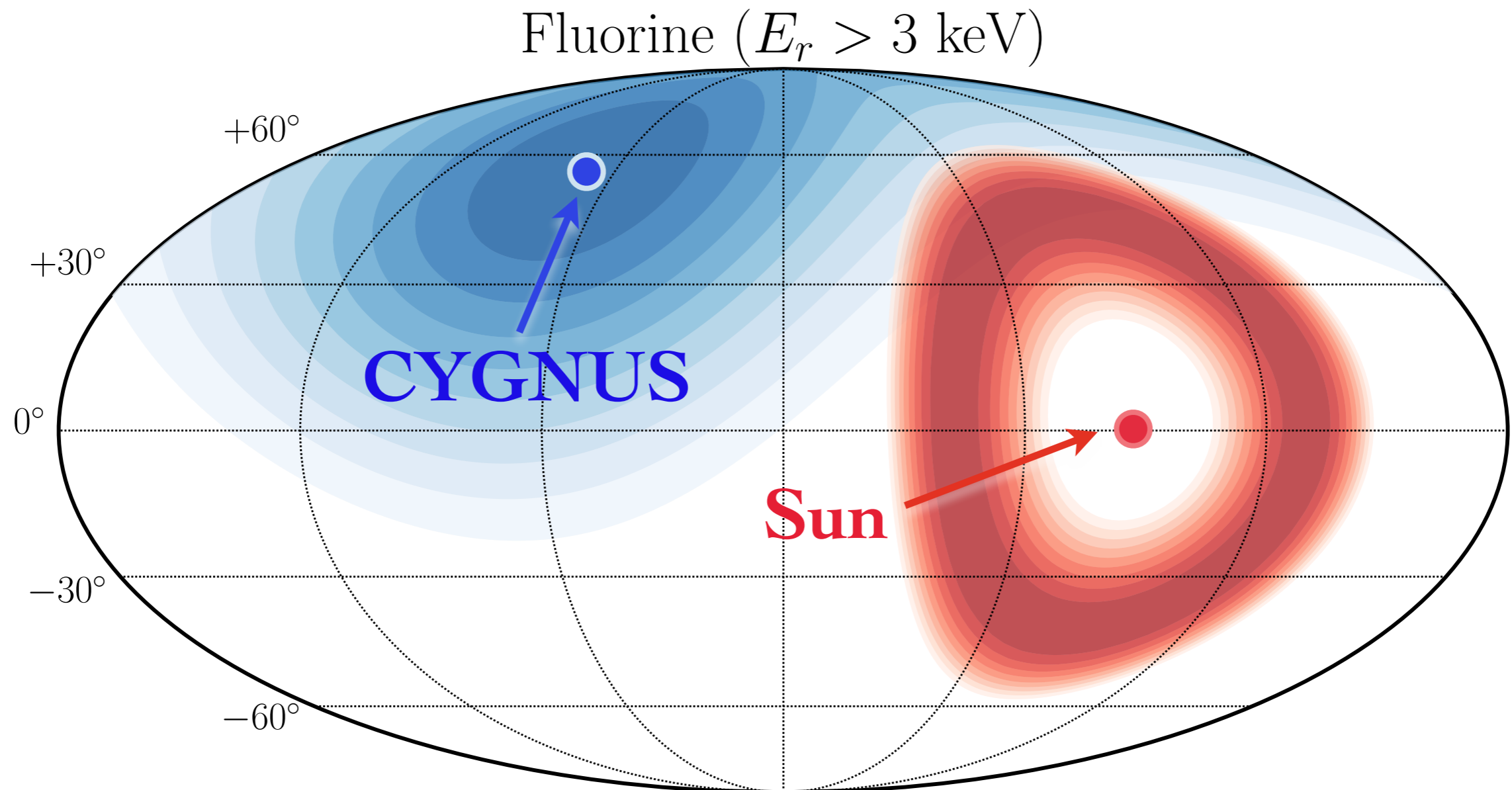


- Planar
- Wire
- Pad
- Optical
- Strip
- Pixel
- Postdrift
- Predrift

By (this) definition: angular resolution of 1 rad and 50% HT efficiency = no directional sensitivity



In a directional detector the neutrino background is reducible because the **DM** & **neutrino** angular distributions have significant non-overlapping parts

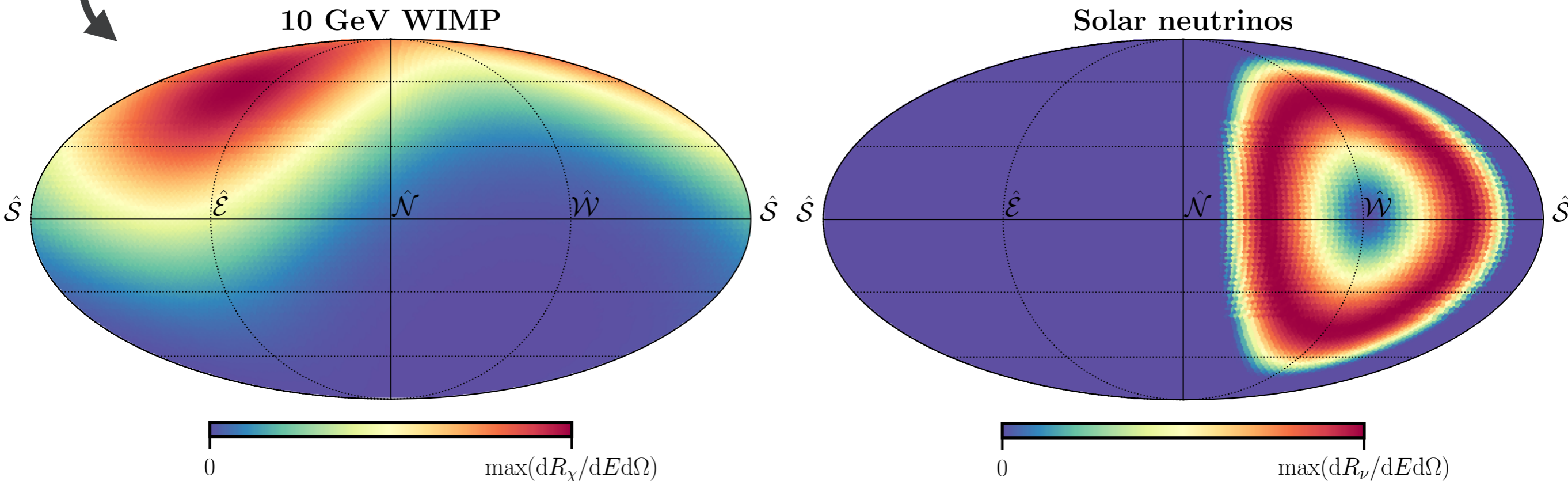


Location: Boulby // Time: 12 Sep. 18:00 GMT

Impact of directional performance

In an imperfect detector, more of the distributions will overlap
Angular resolution \rightarrow smears distributions in angle
No head-tail \rightarrow folds one half of sky on to the other

Recoil maps for **perfect direction reconstruction**:



(F¹⁹ rate integrated above 3 keVr threshold)

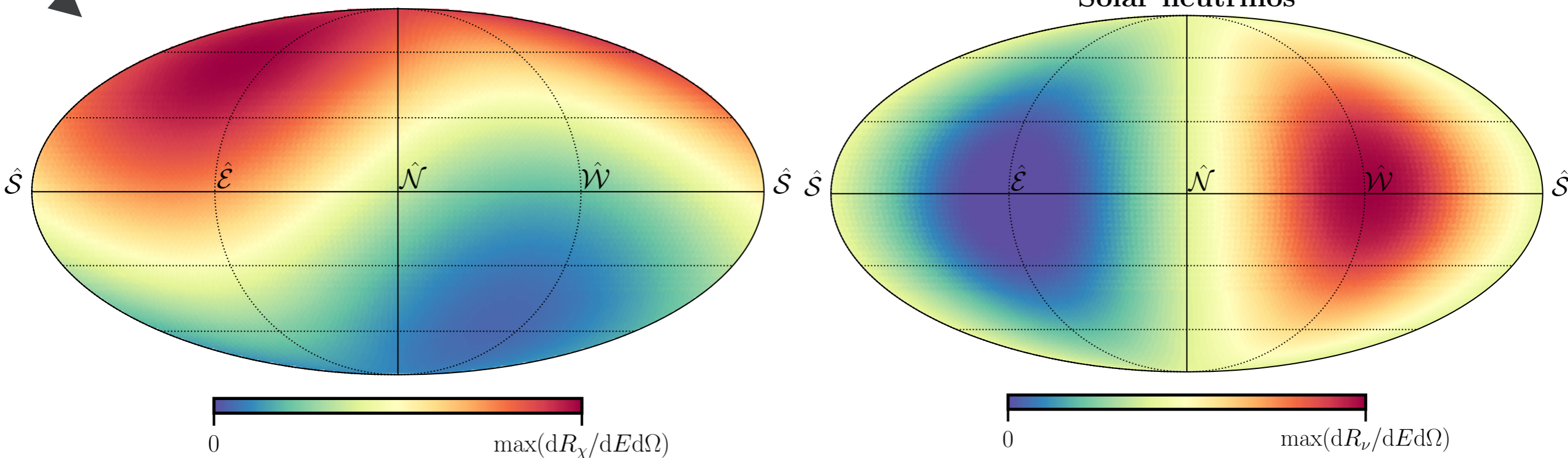
Impact of directional performance

In an imperfect detector, more of the distributions will overlap
Angular resolution \rightarrow smears distributions in angle
No head-tail \rightarrow folds one half of sky on to the other

After pixel post-drift **angular resolution** applied

10 GeV WIMP

Solar neutrinos



(F¹⁹ rate integrated above 3 keVr threshold)

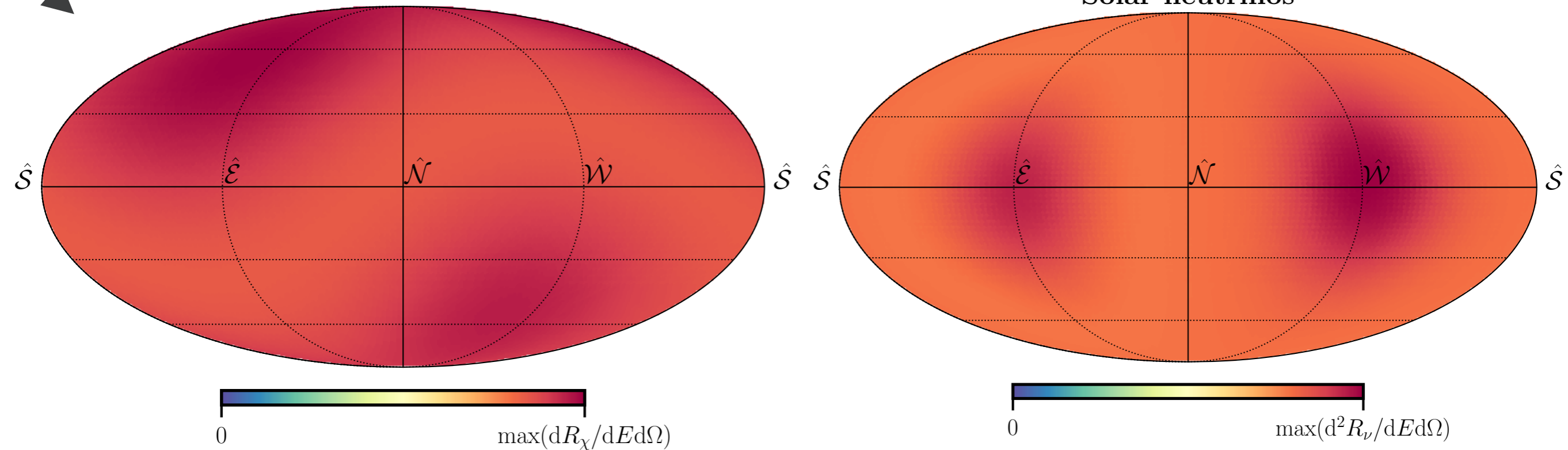
Impact of directional performance

In an imperfect detector, more of the distributions will overlap
Angular resolution \rightarrow smears distributions in angle
No head-tail \rightarrow folds one half of sky on to the other

Recoil maps after **angular resolution** and **HT efficiency** applied

10 GeV WIMP

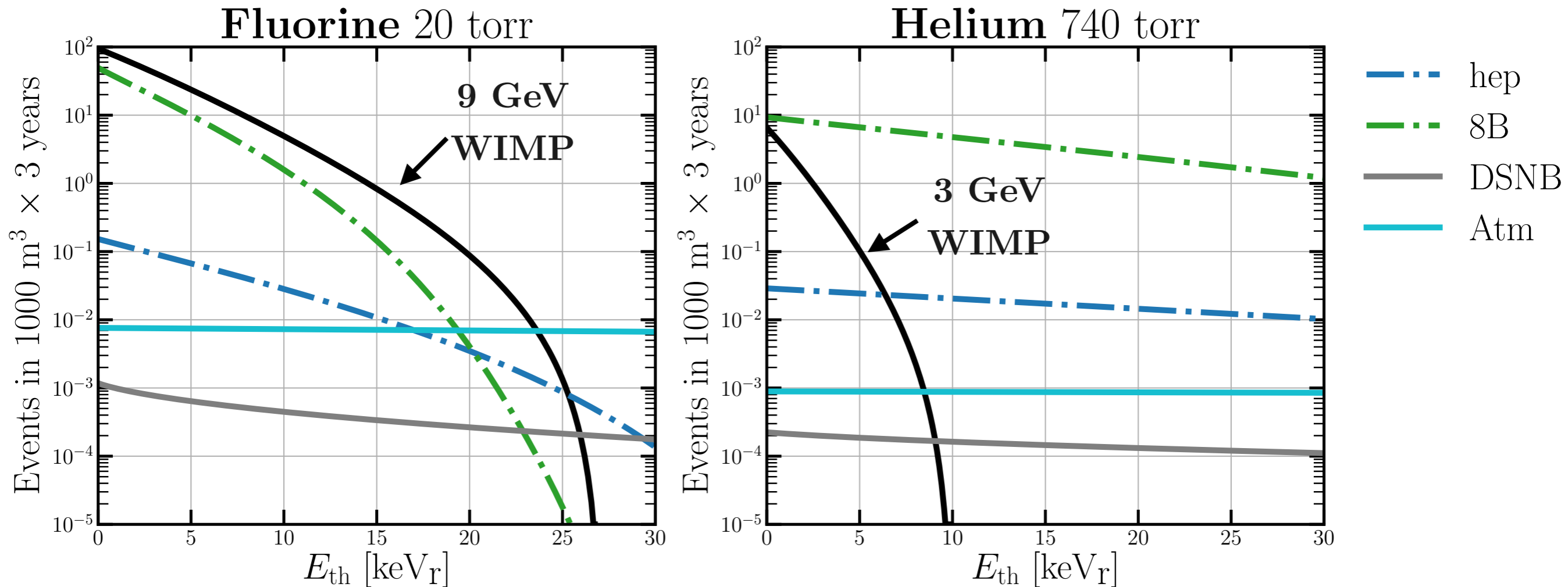
Solar neutrinos



(F^{19} rate integrated above 3 keVr threshold)

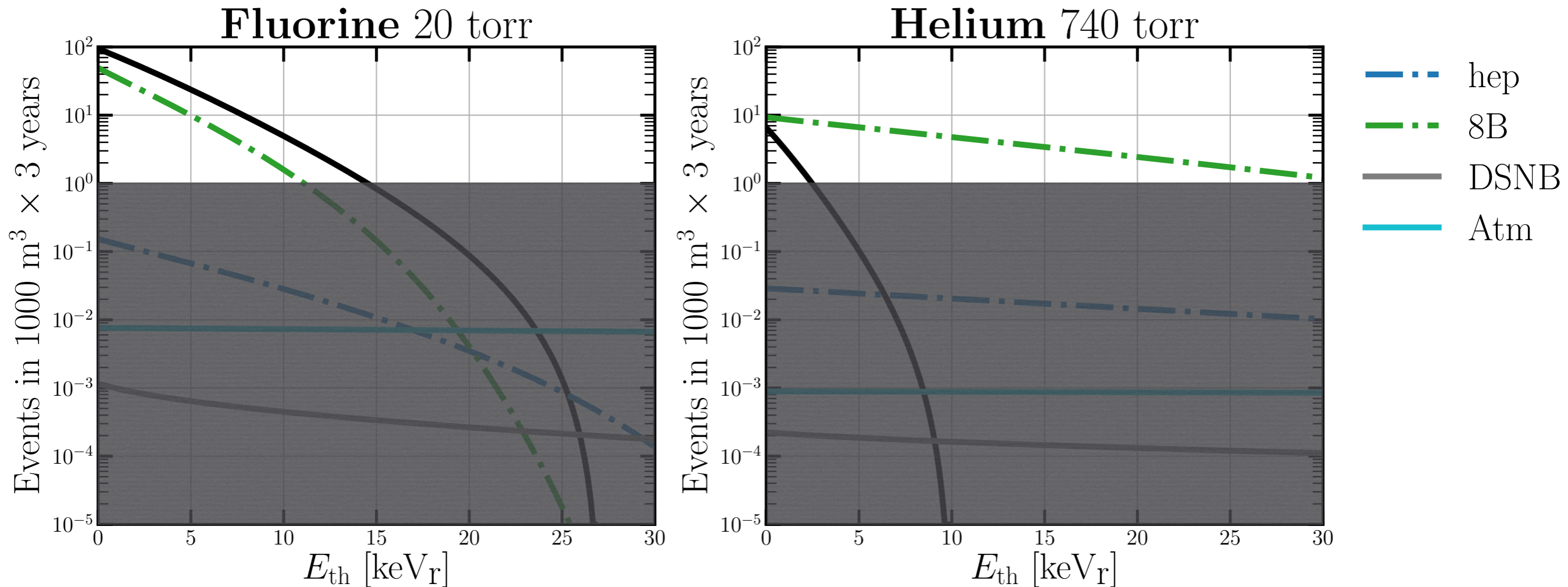
Neutrino background

Number of events above a NR threshold
($1000 \text{ m}^3 \times 3 \text{ years}$)

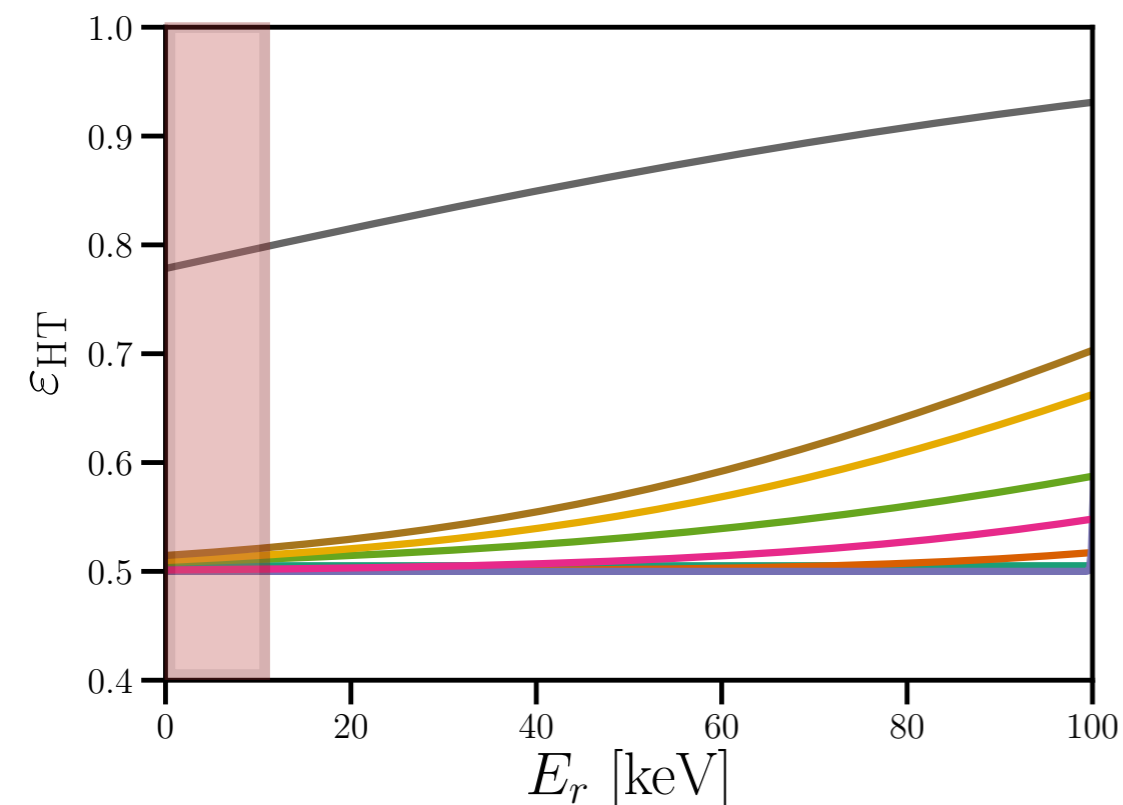
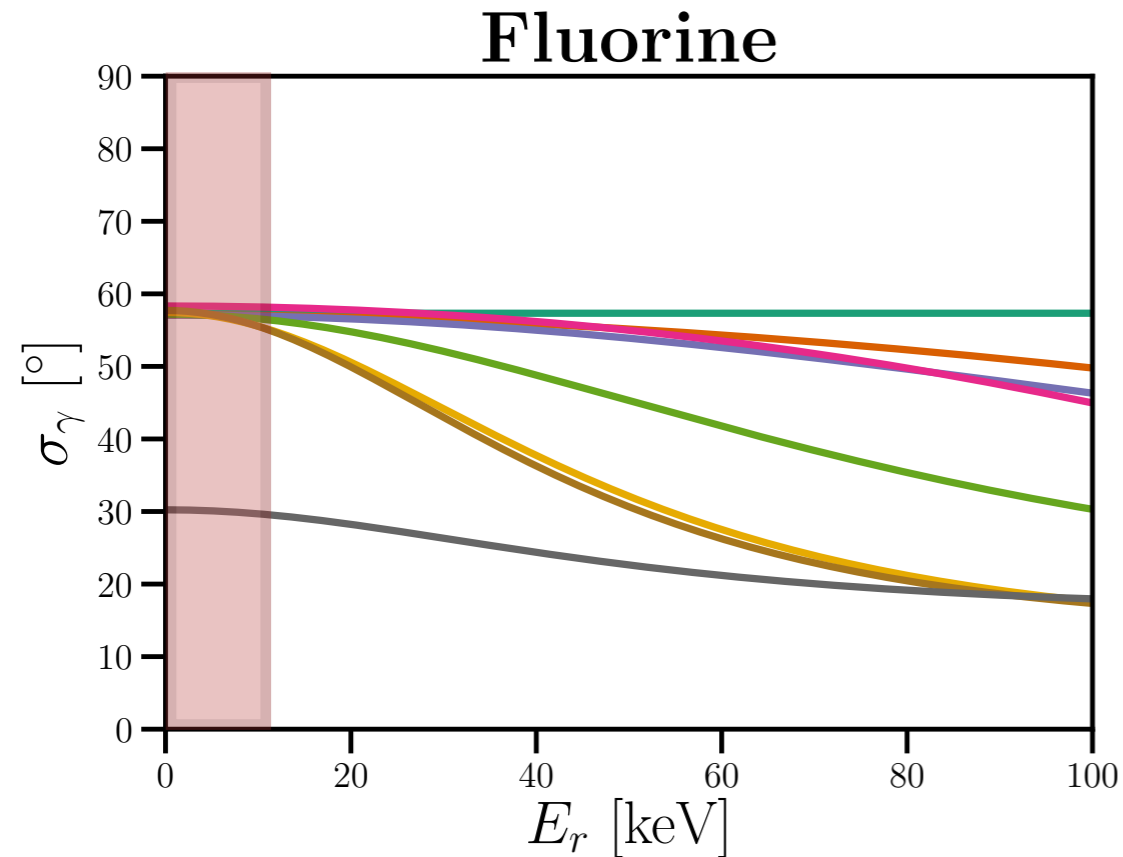


Neutrino background

Number of events above a NR threshold
($1000 \text{ m}^3 \times 3 \text{ years}$)



Neutrino background



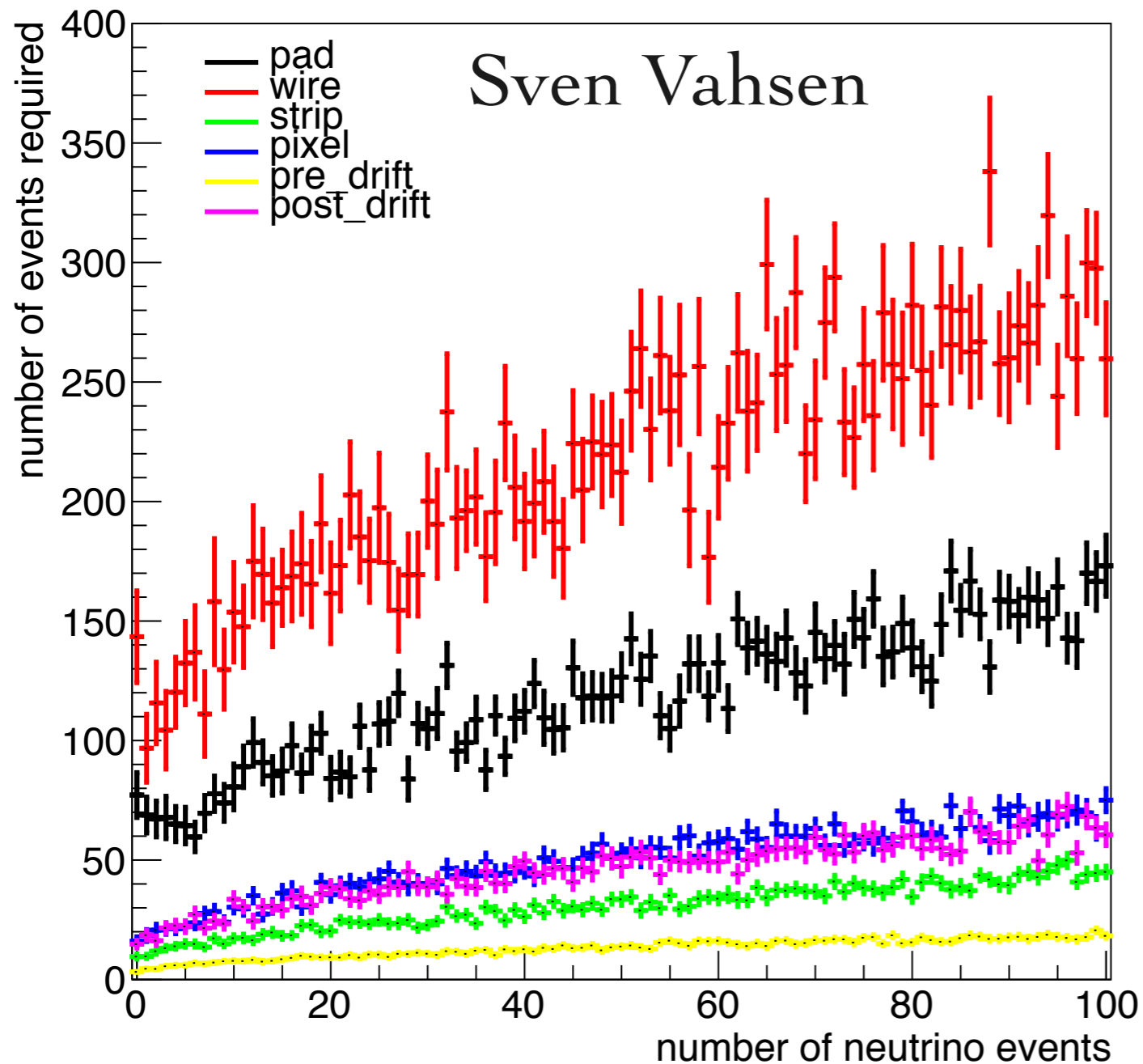
For CYGNUS-1000 (F), in 3 years < 1 exp. neutrino event scattering above 12 keV



For nu floor: only readout performance for $E_r < 12$ keV is relevant

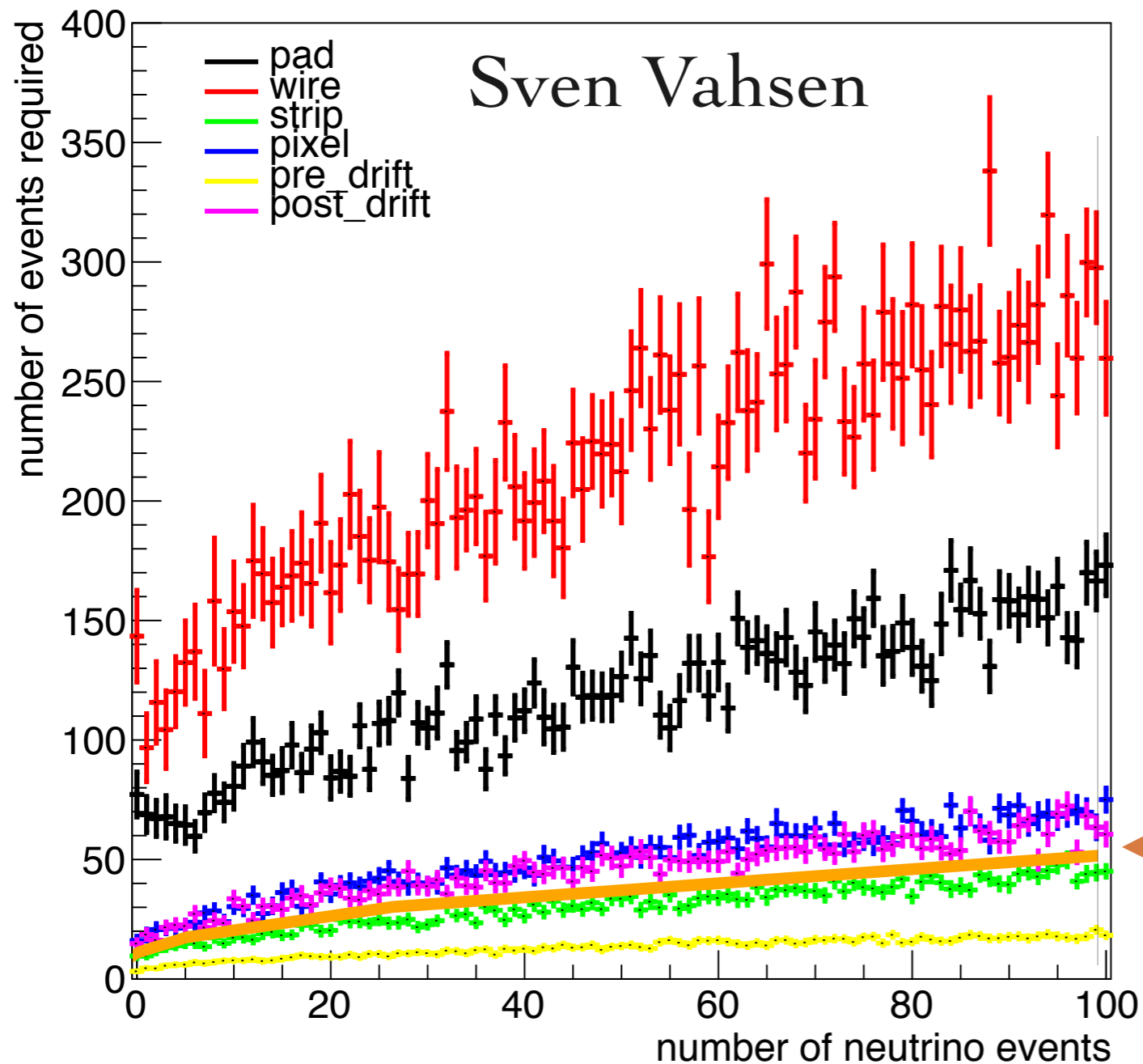
Neutrino background

events needed for 90% CL discrimination between 10 GeV
WIMP and neutrinos



Neutrino background

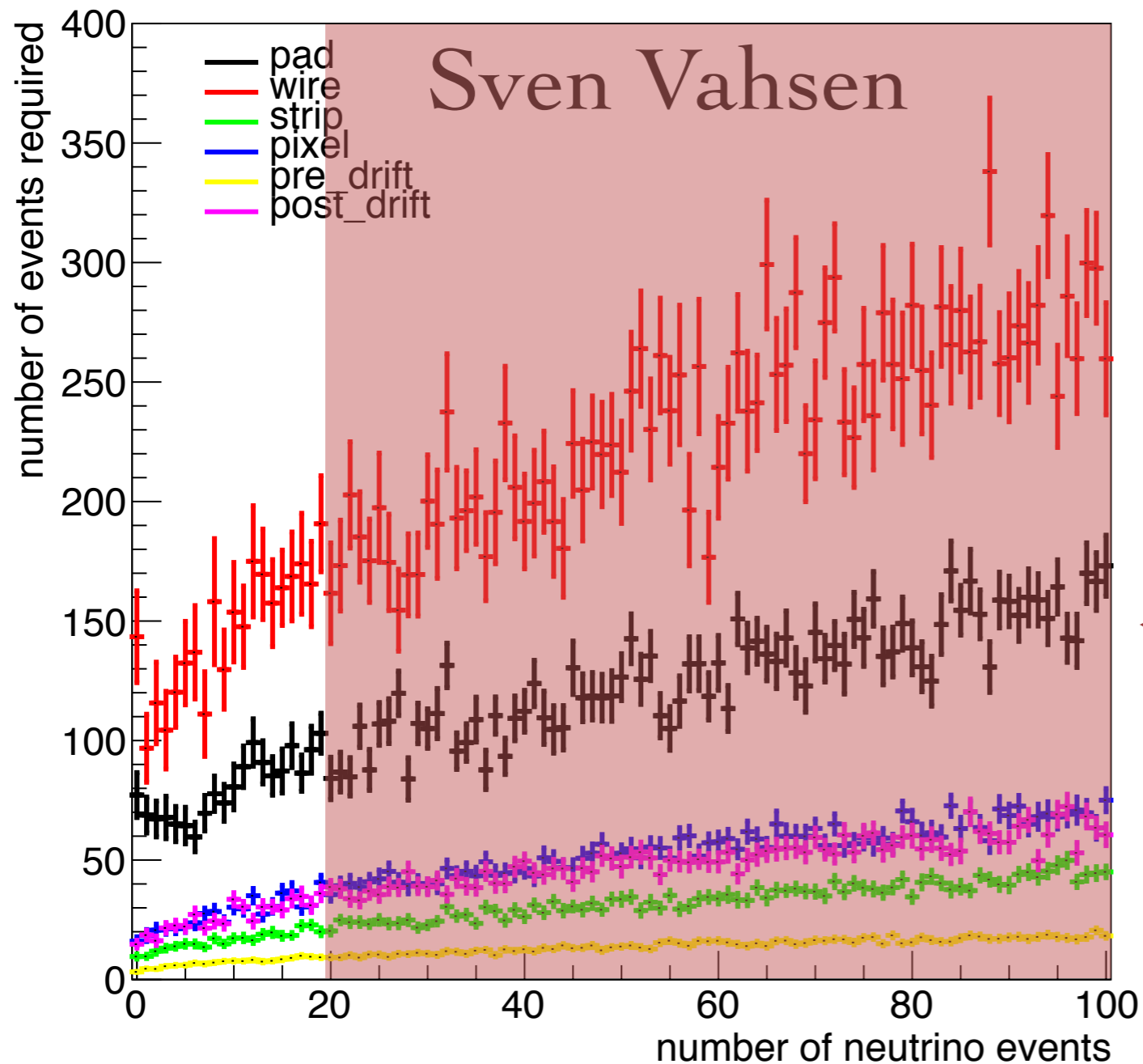
events needed for 90% CL discrimination between 10 GeV
WIMP and neutrinos



Number of events
required when using
recoil energy
information

Neutrino background

events needed for 90% CL discrimination between 10 GeV
WIMP and neutrinos



Requires
 $\text{Vol} > 1000 \text{ m}^3$



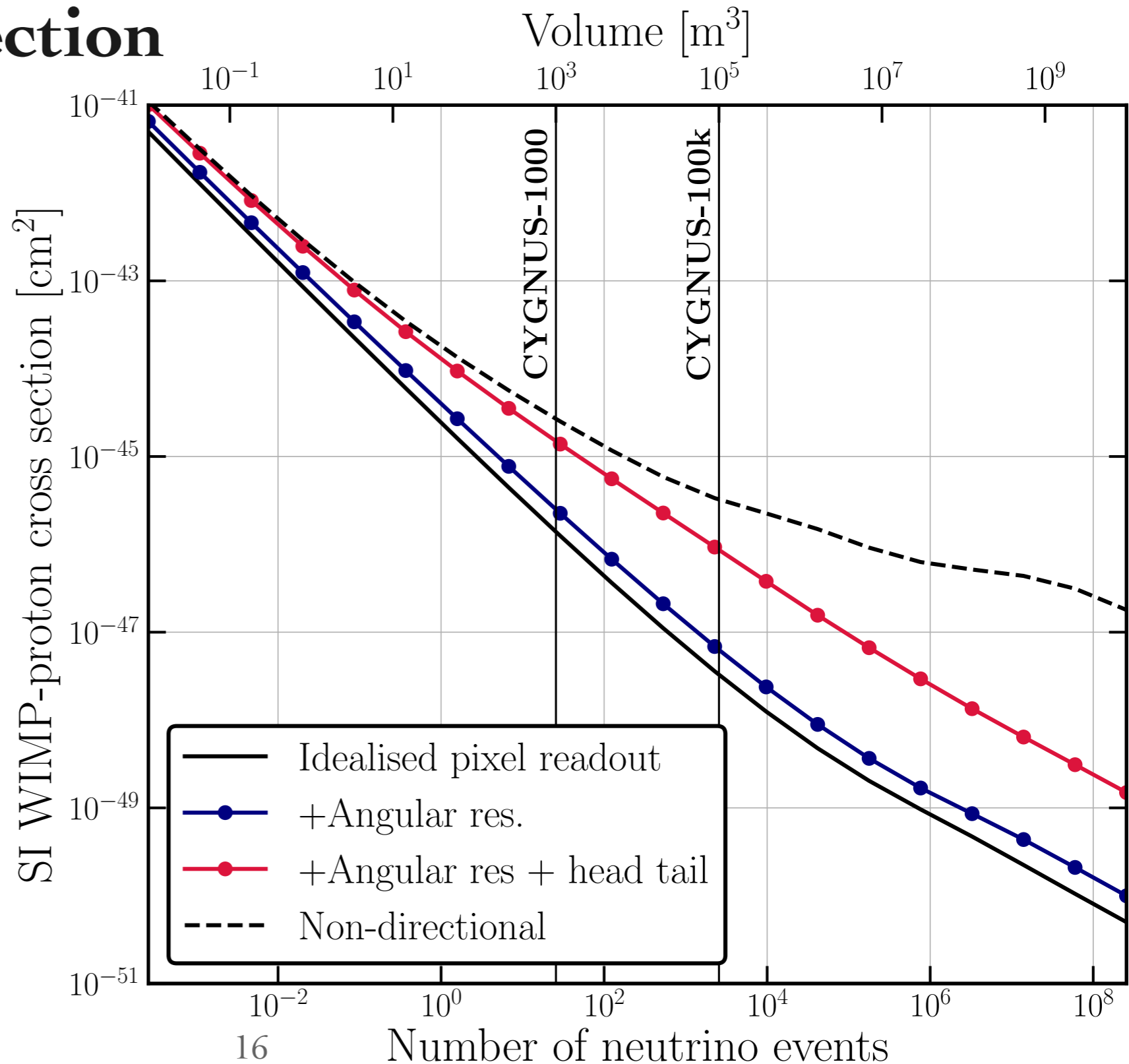
Subtracting the neutrino background

Same as Sven's plot (previous slide) but as a function of cross section

Min. discoverable cross section vs number of neutrino events

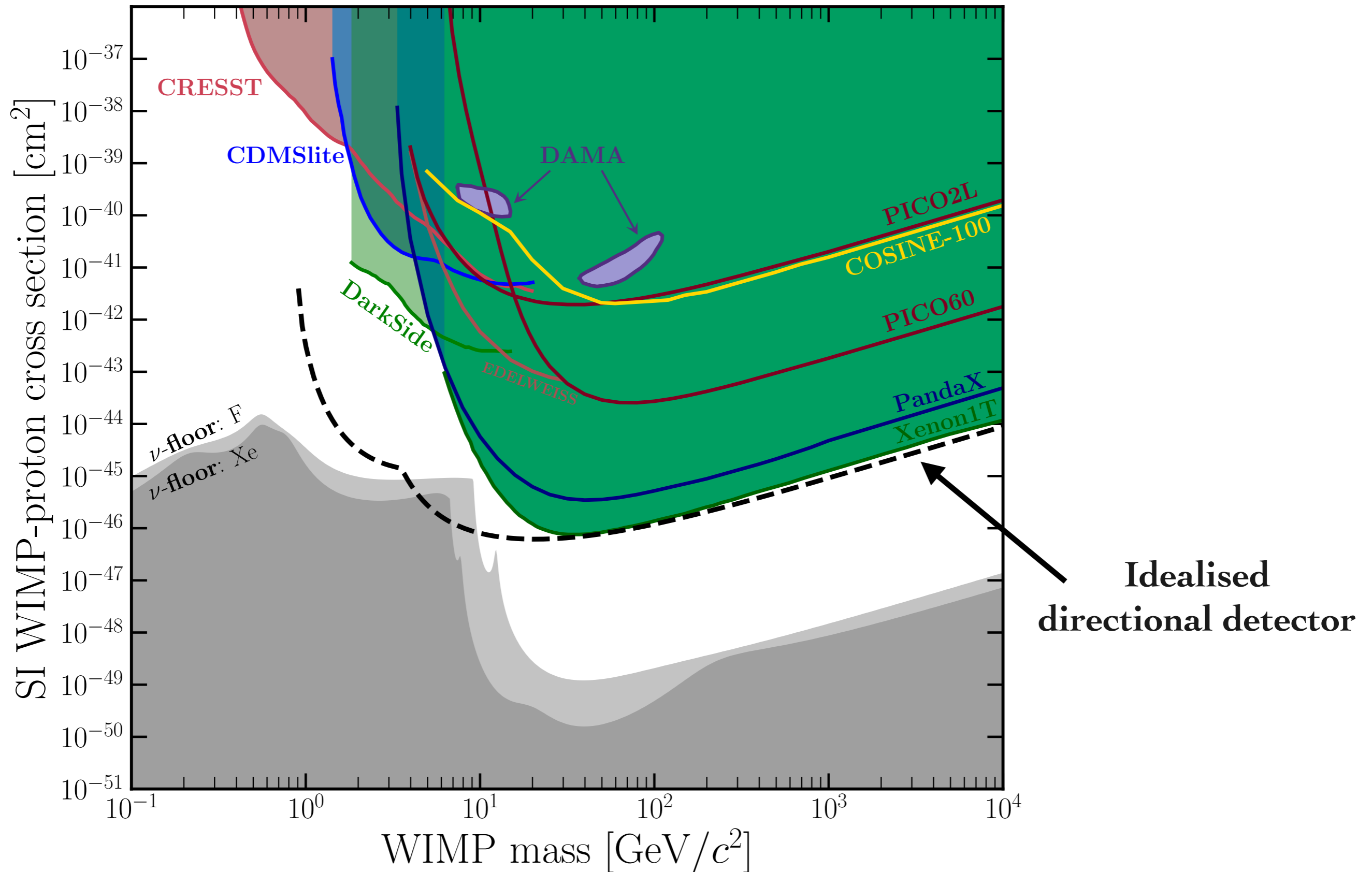


(10 GeV WIMP)



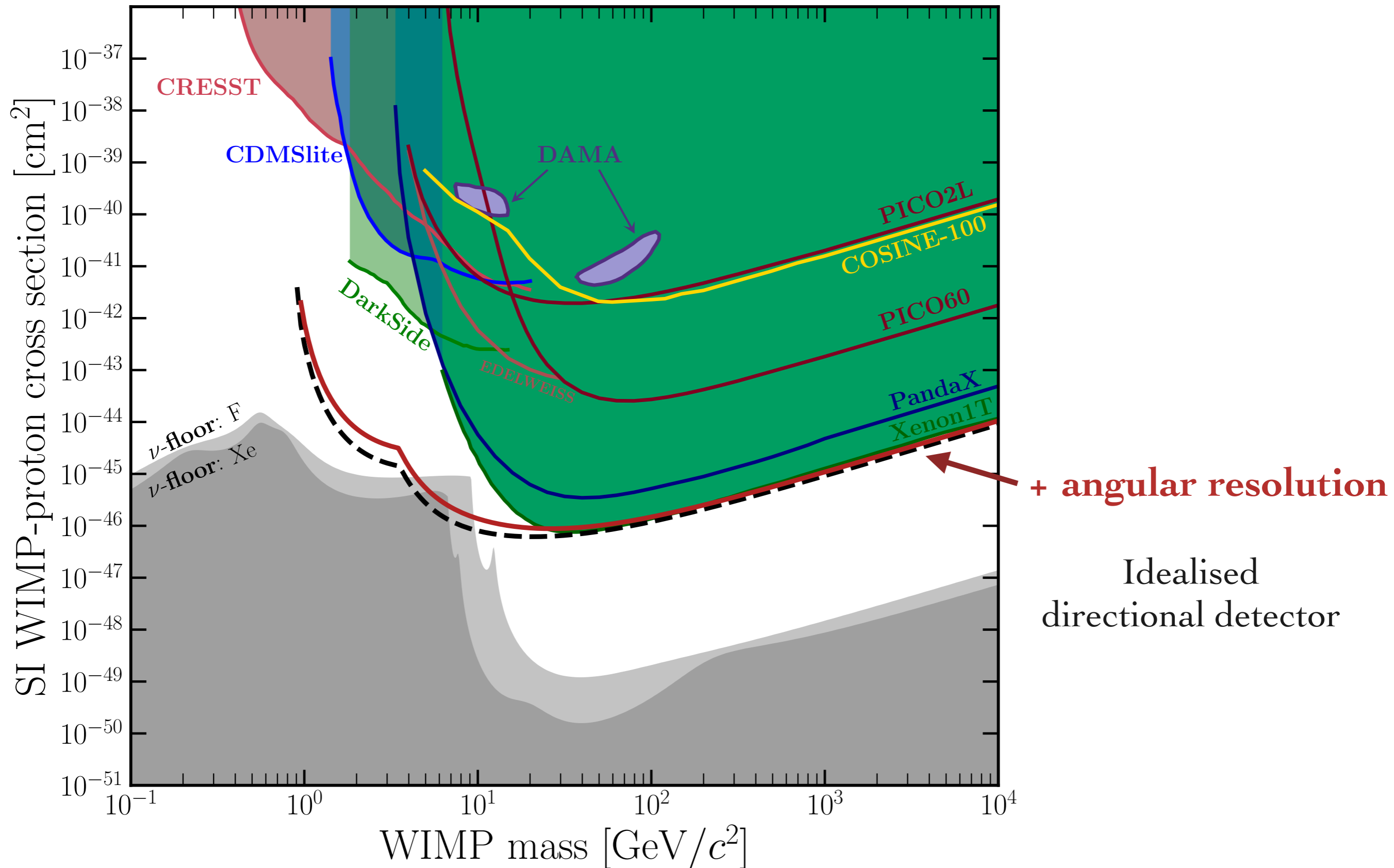
Spin independent reach

(CYGNUS 1000 \times 6 years)



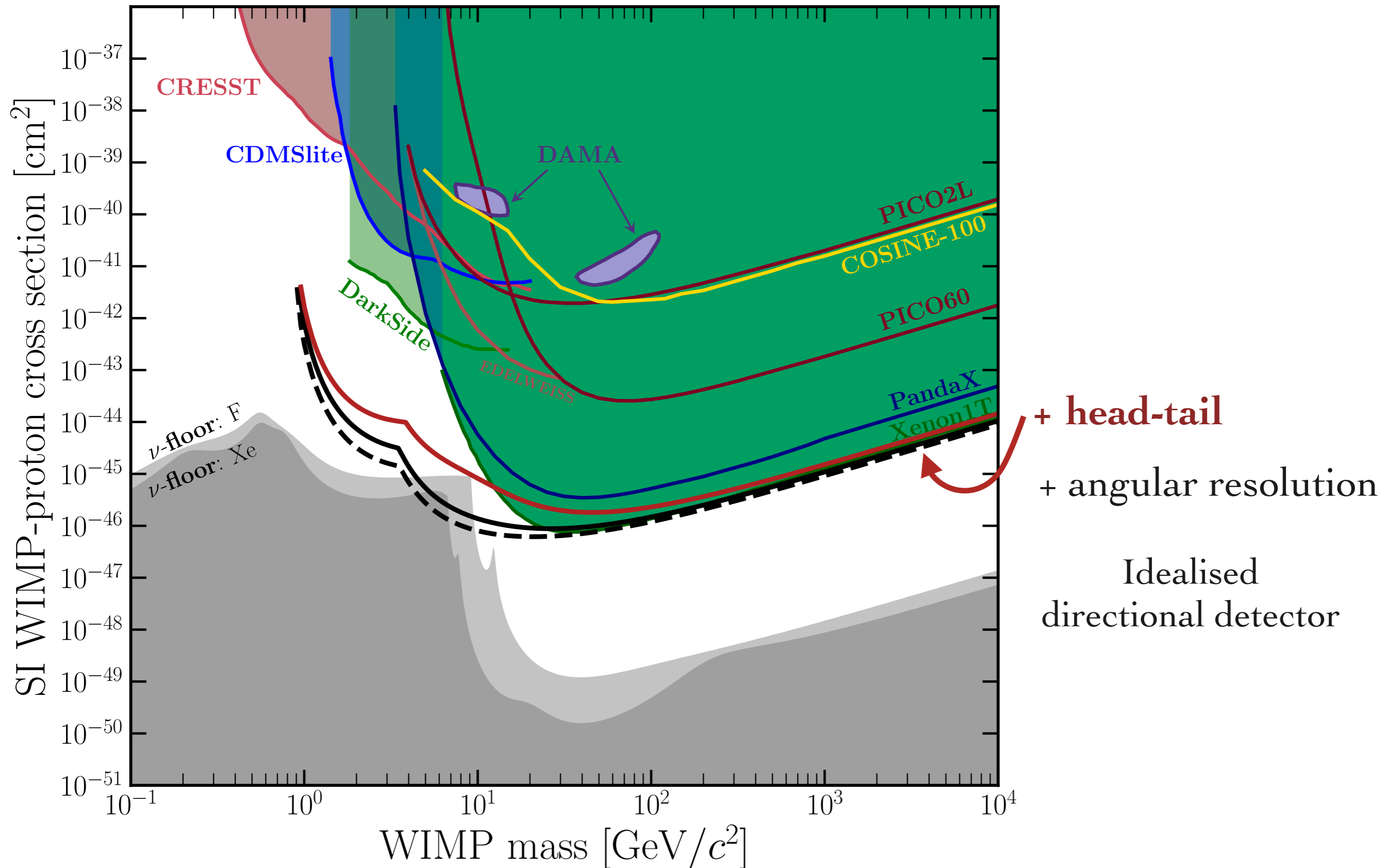
Spin independent reach

(CYGNUS 1000 \times 6 years)



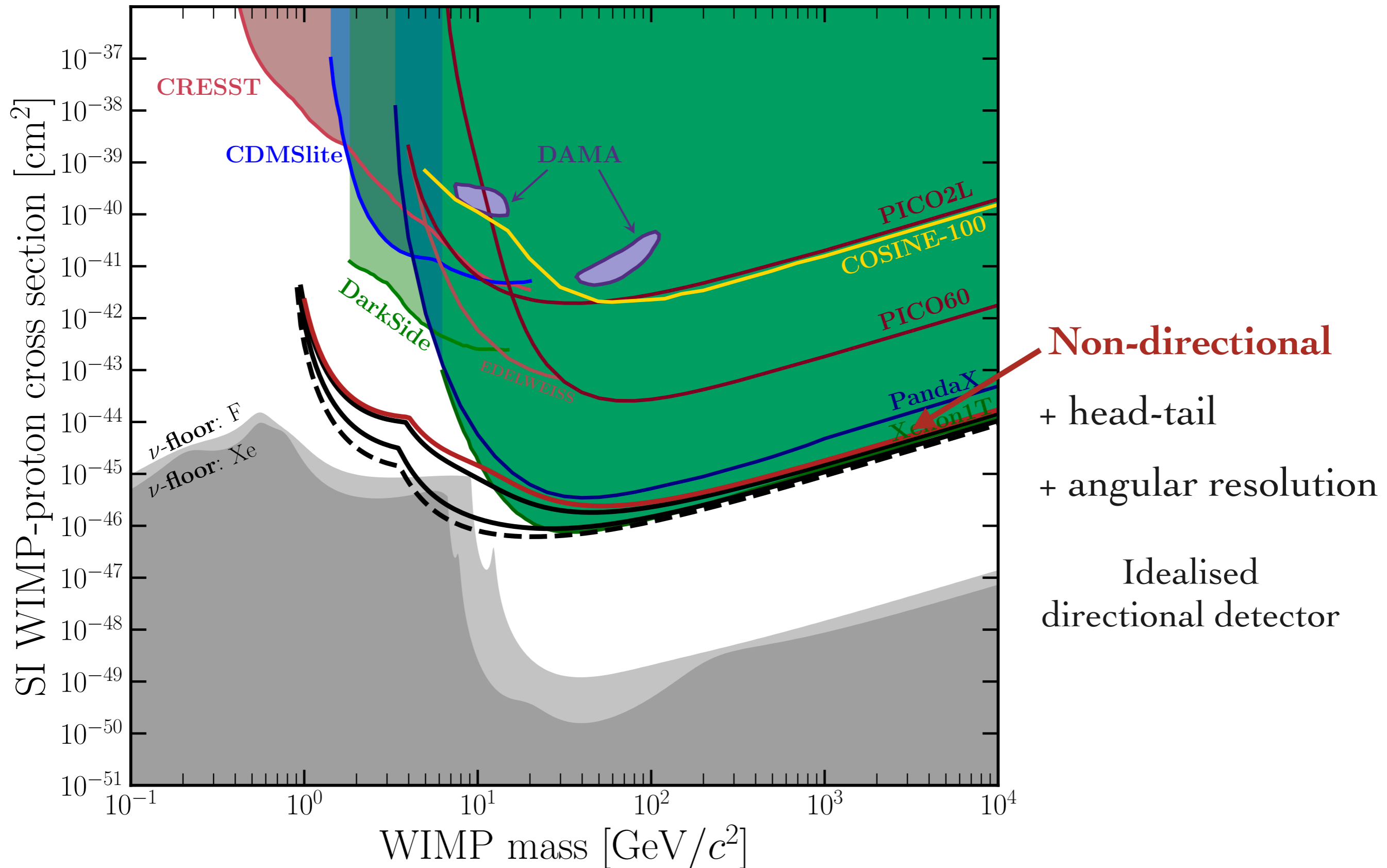
Spin independent reach

(CYGNUS 1000 × 6 years)



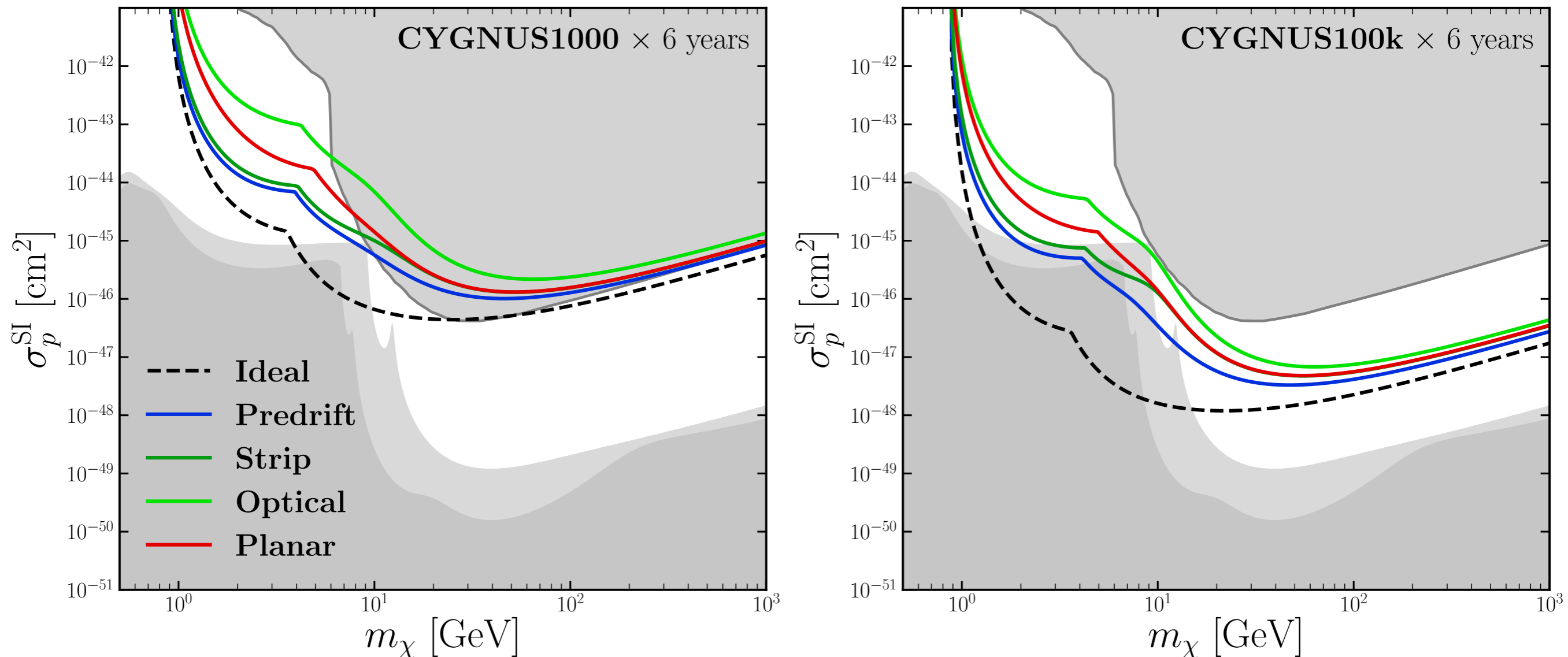
Spin independent reach

(CYGNUS 1000 × 6 years)



Readout comparison

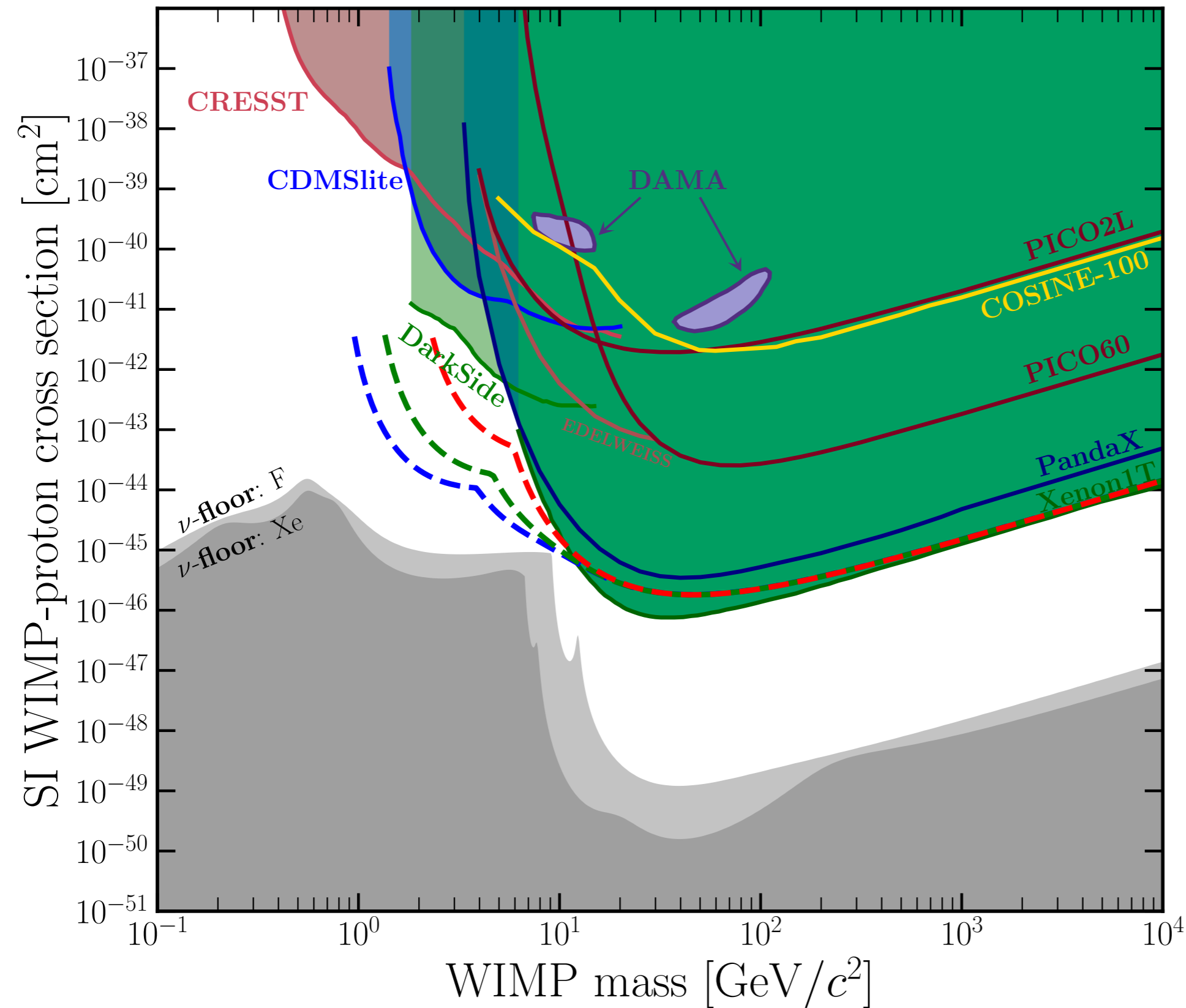
Only a subset of all readouts shown since all examples with poorer performance than **strip** do not gain in sensitivity from their directionality



Optical and **Planar** suffer due to poorer detection efficiency

Spin independent reach

(CYGNUS 1000 × 6 years)



Dependence on thresholds:

1 keV (He)

3 keV (F)

3 keV (He)

5 keV (F)

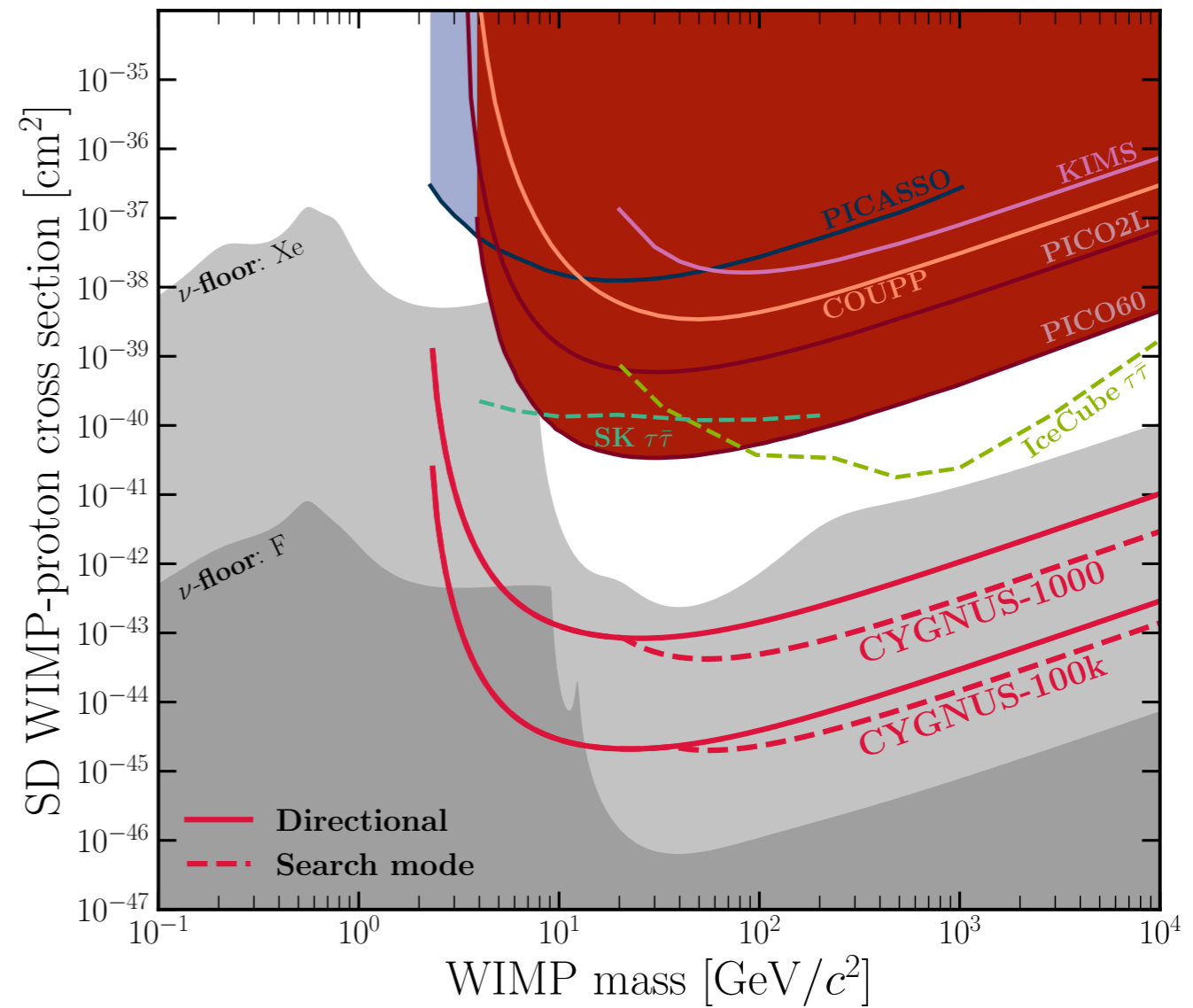
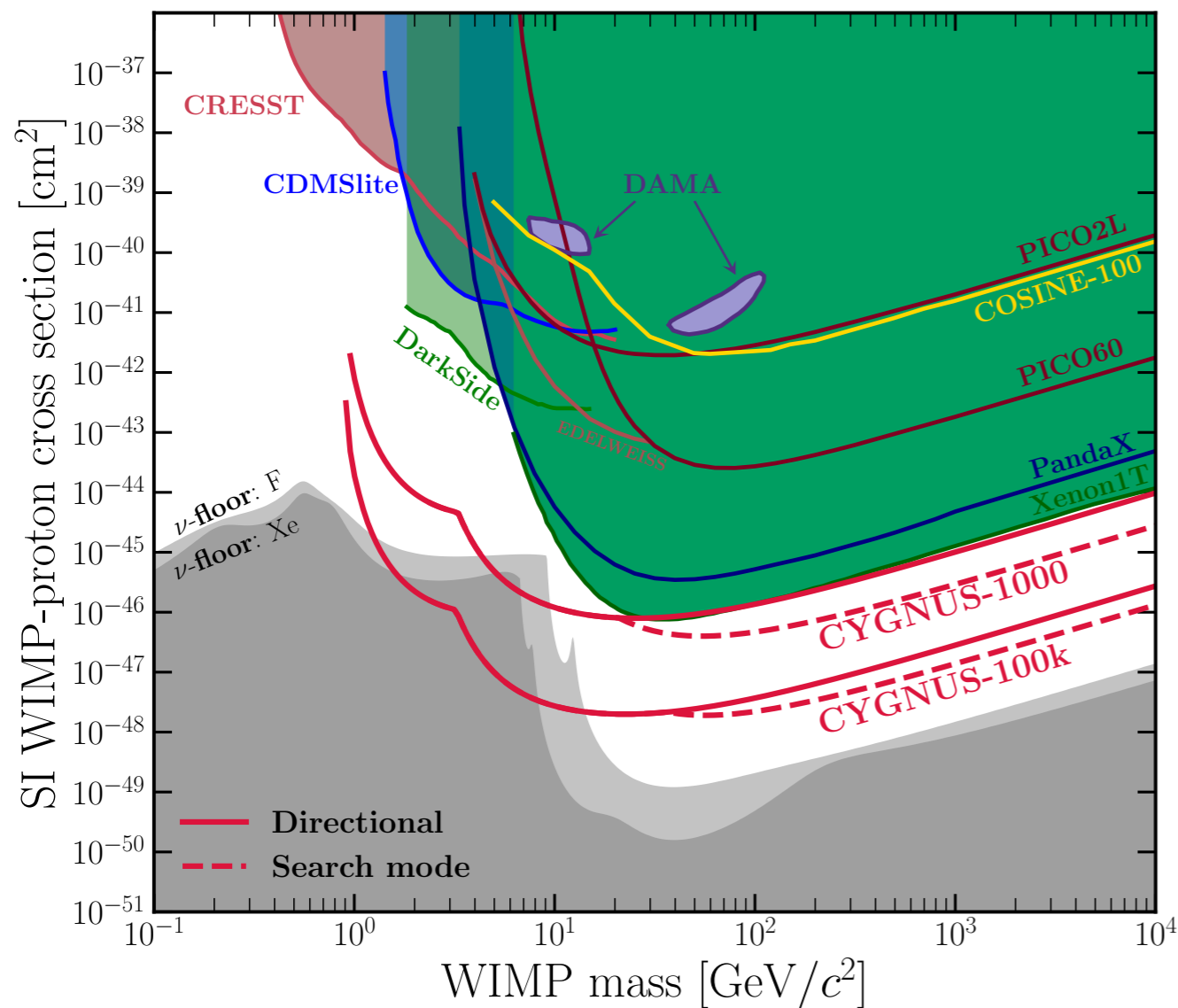
6 keV (He)

10 keV (F)

Final reach plots

CYGNUS1000/100k, Direction/search modes

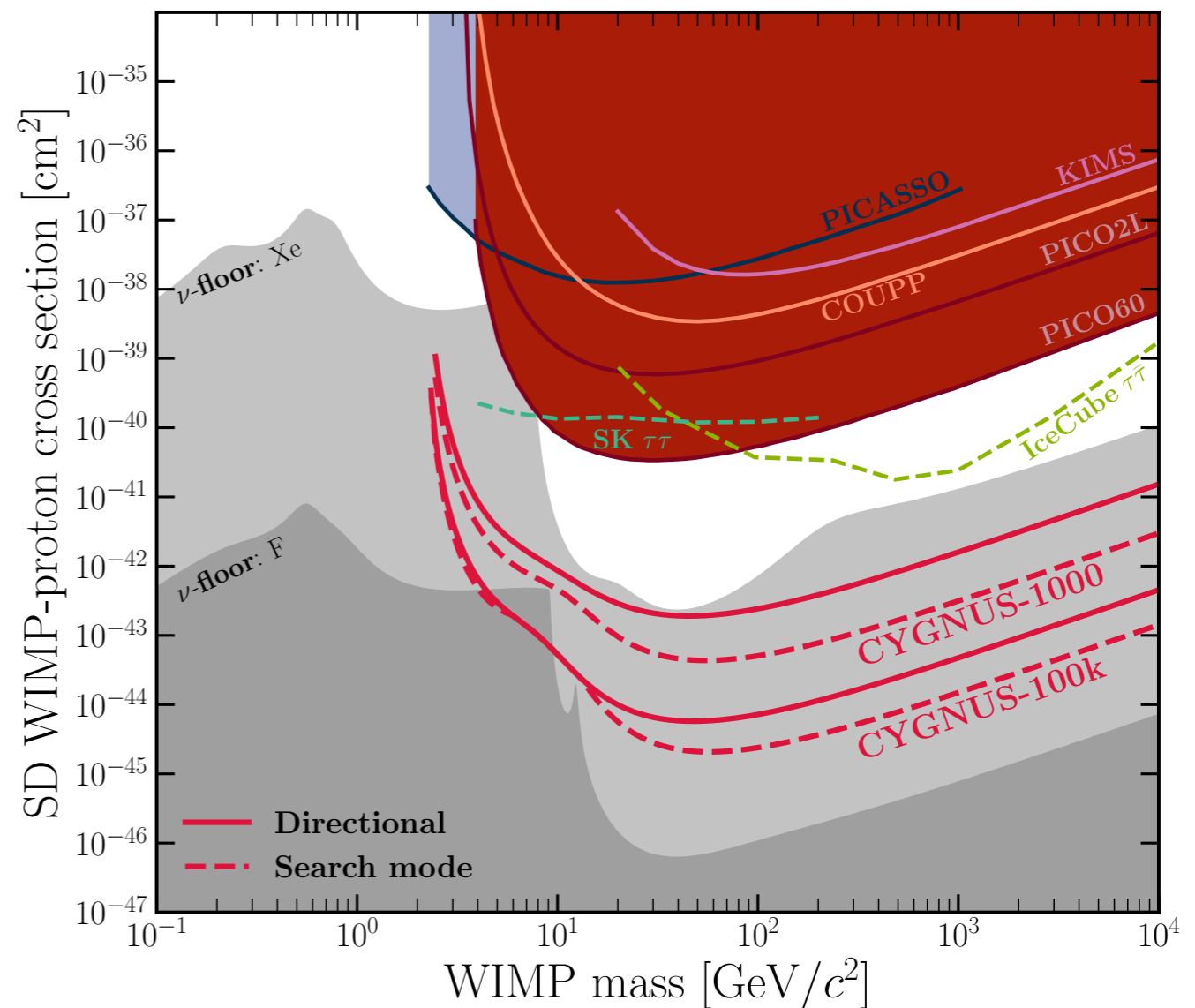
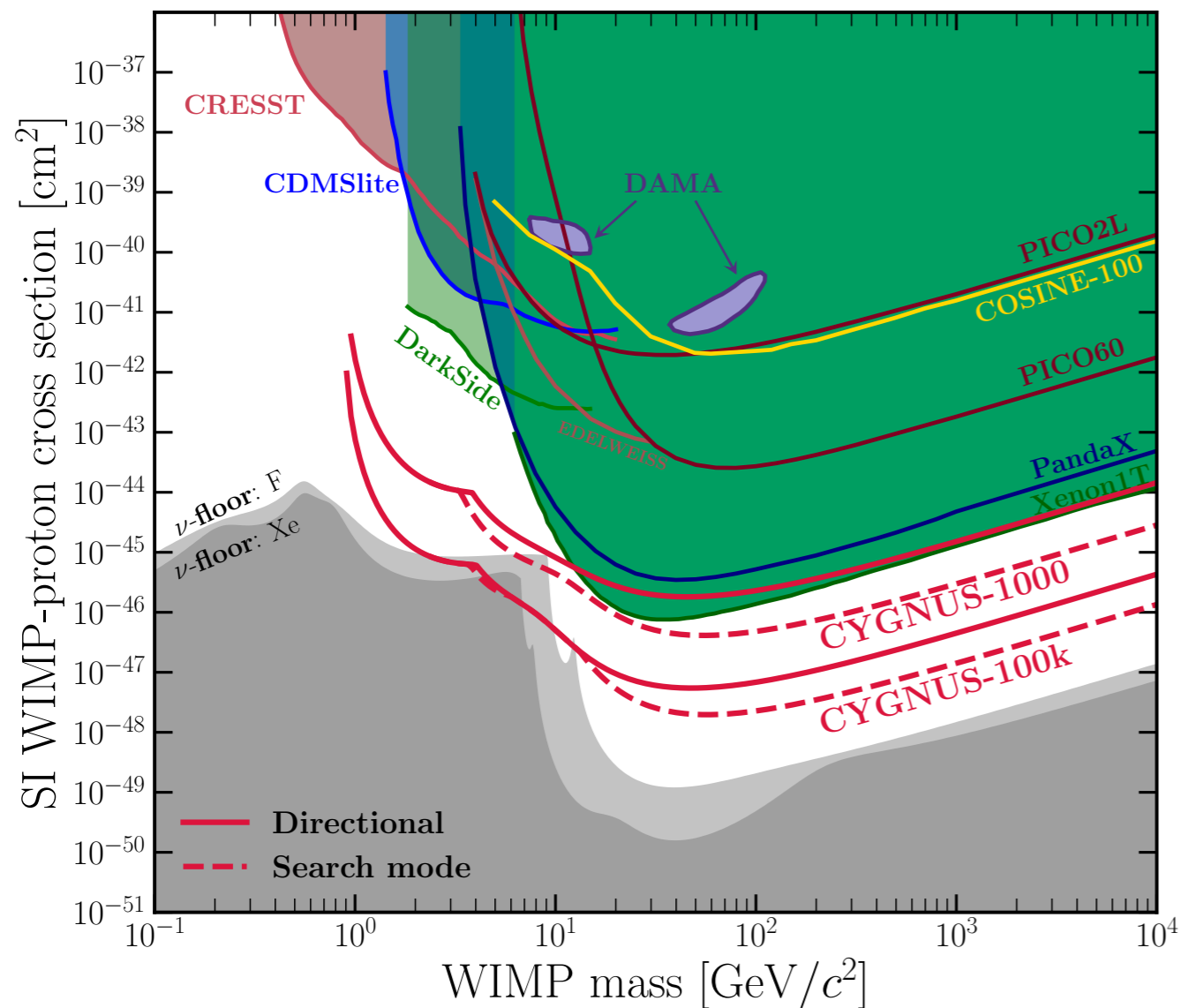
Option 1: show idealised projections



Final reach plots

CYGNUS1000/100k, Direction/search modes

Option 2: show pre-drift sensitivity



Conclusions 1

The harsh reality:

- For neutrino floor, need to focus on readout performance for recoil energies < 10 keV
- If performance < 10 keV is not better than ~ 50 deg angular resolution, and $\sim 75\%$ HT efficiency then directionality adds nothing over a non-directional equivalent
- If F threshold < 5 keV is not justifiable then we cannot claim to subtract ν background with F
- If $\text{Vol} > 1000 \text{ m}^3$ is not justifiable then we cannot claim to subtract ν background with He

Conclusions 2

The good news:

- The pre-drift performance is sufficient to start going beyond the neutrino floor
- SD limits will be highly competitive regardless of readout thanks to ^{19}F
- Still good astrophysics reach for pixel and strip readouts

More physics (discussed in paper, but needs work):

Axion-like particles, superheavy WIMPs, DM-electron scattering, velocity dependent operators, neutrinos

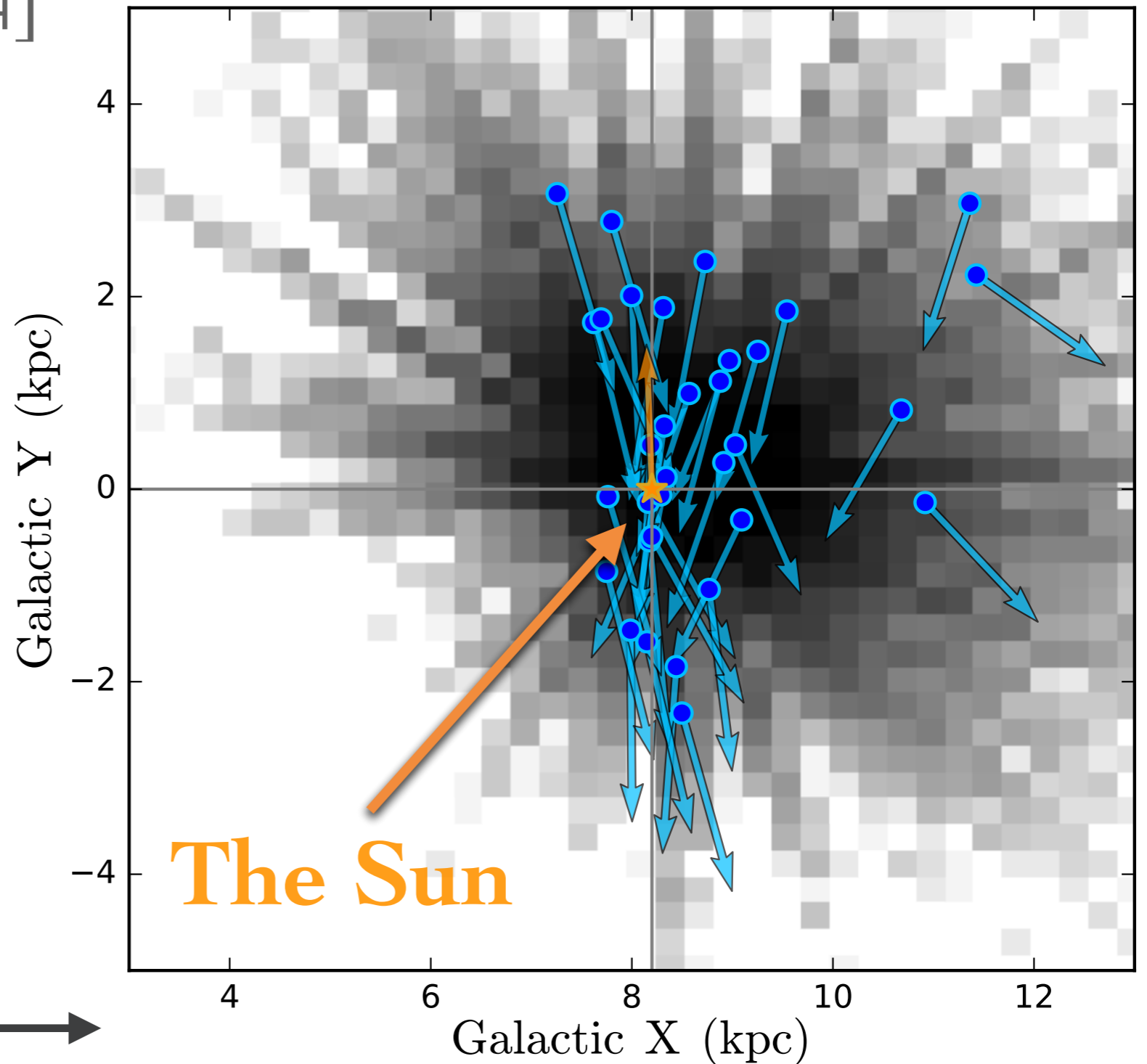
The S1 stream

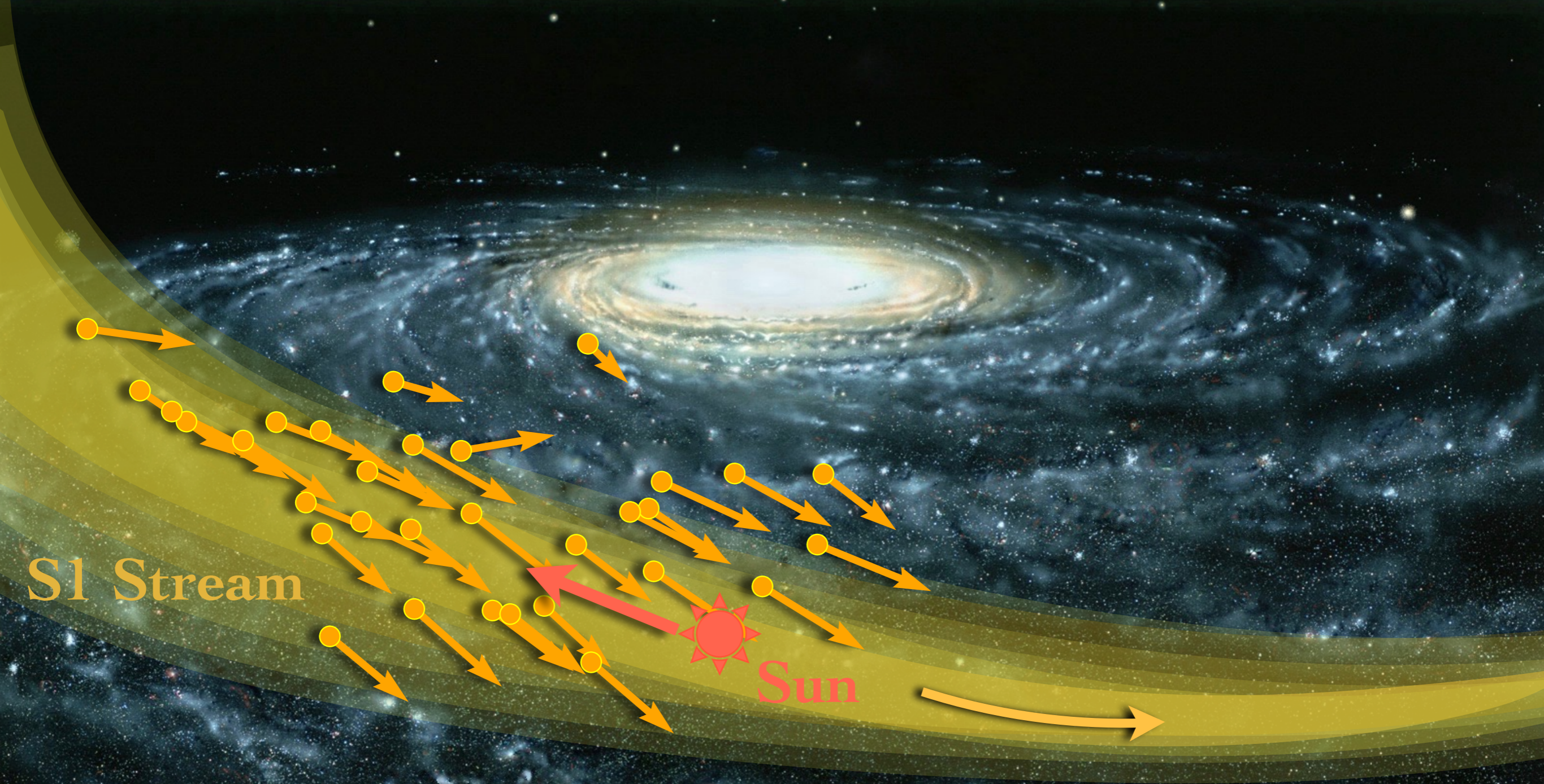
O'Hare et al. [1807.09004]

S1 stream

→ Found in Gaia
DR2,
→ Stream
intersecting **Solar
neighbourhood**

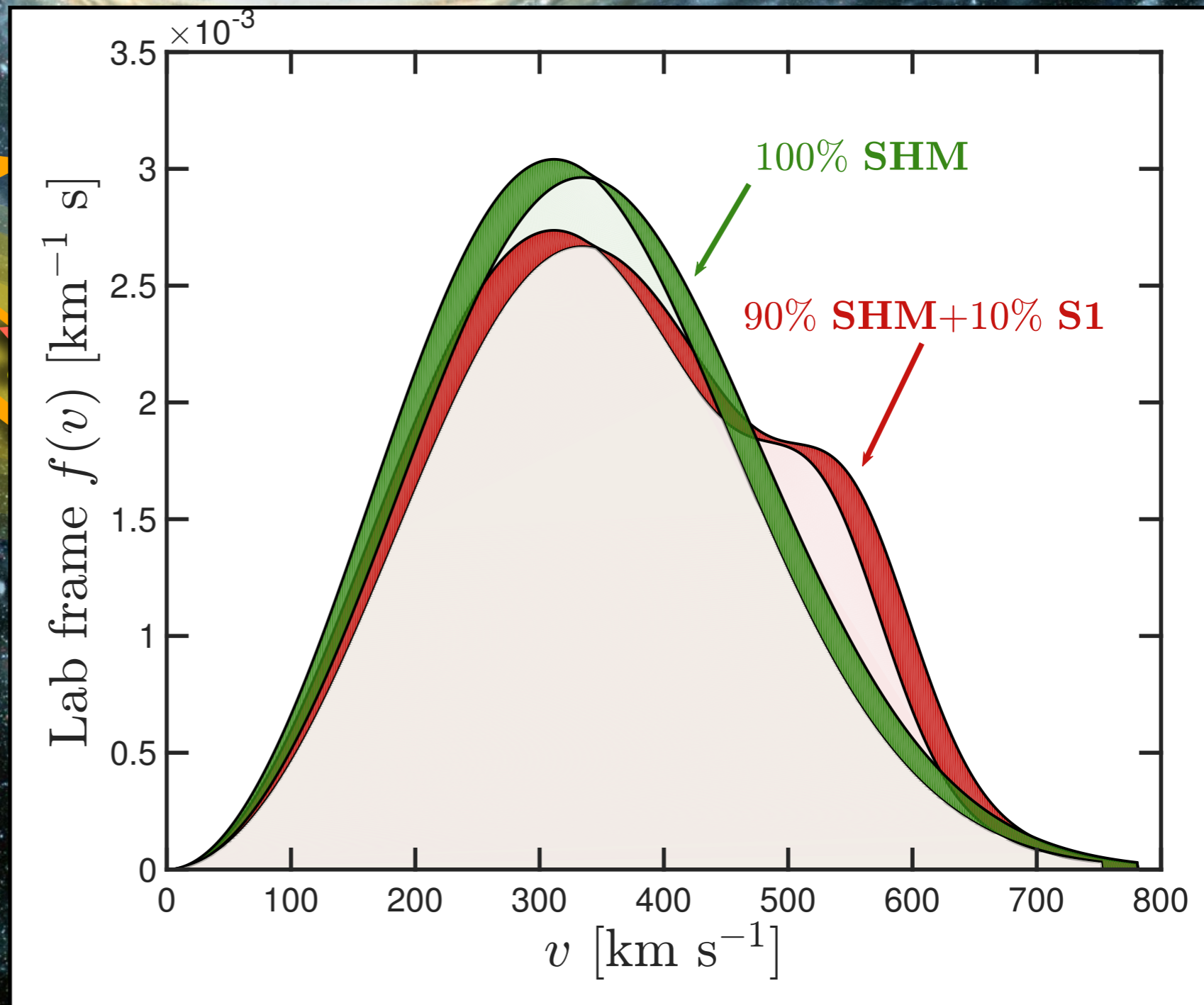
Galactic
plane



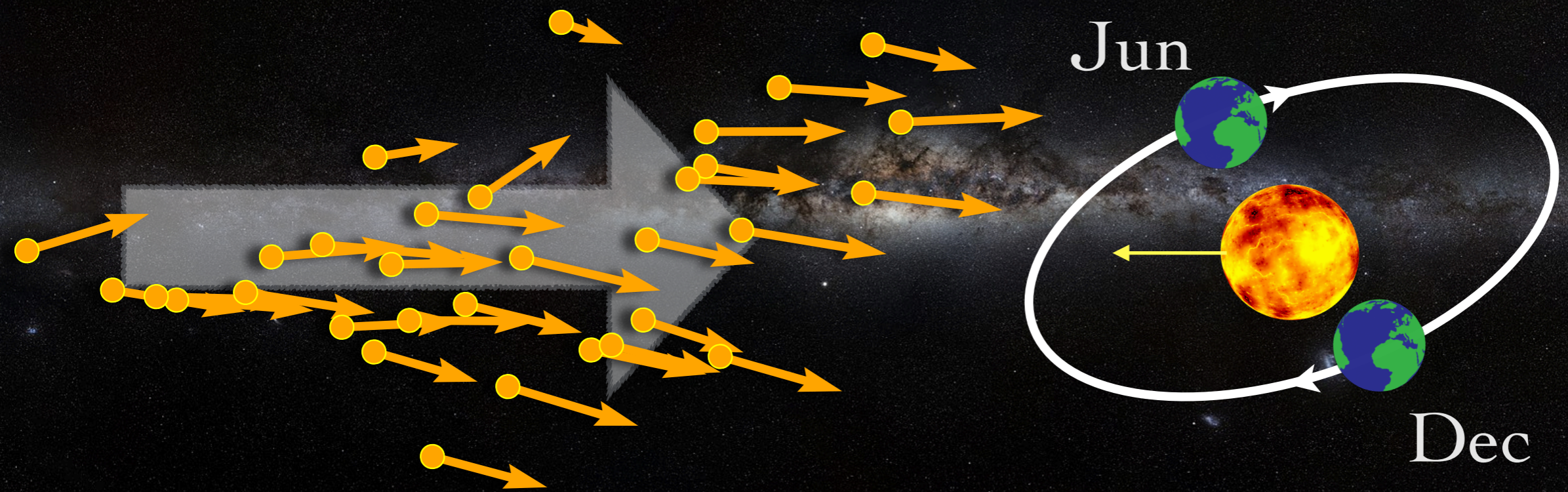


S1 stream impacting the solar system at high speeds
Dark matter wind → A dark matter hurricane?

Modelling S1

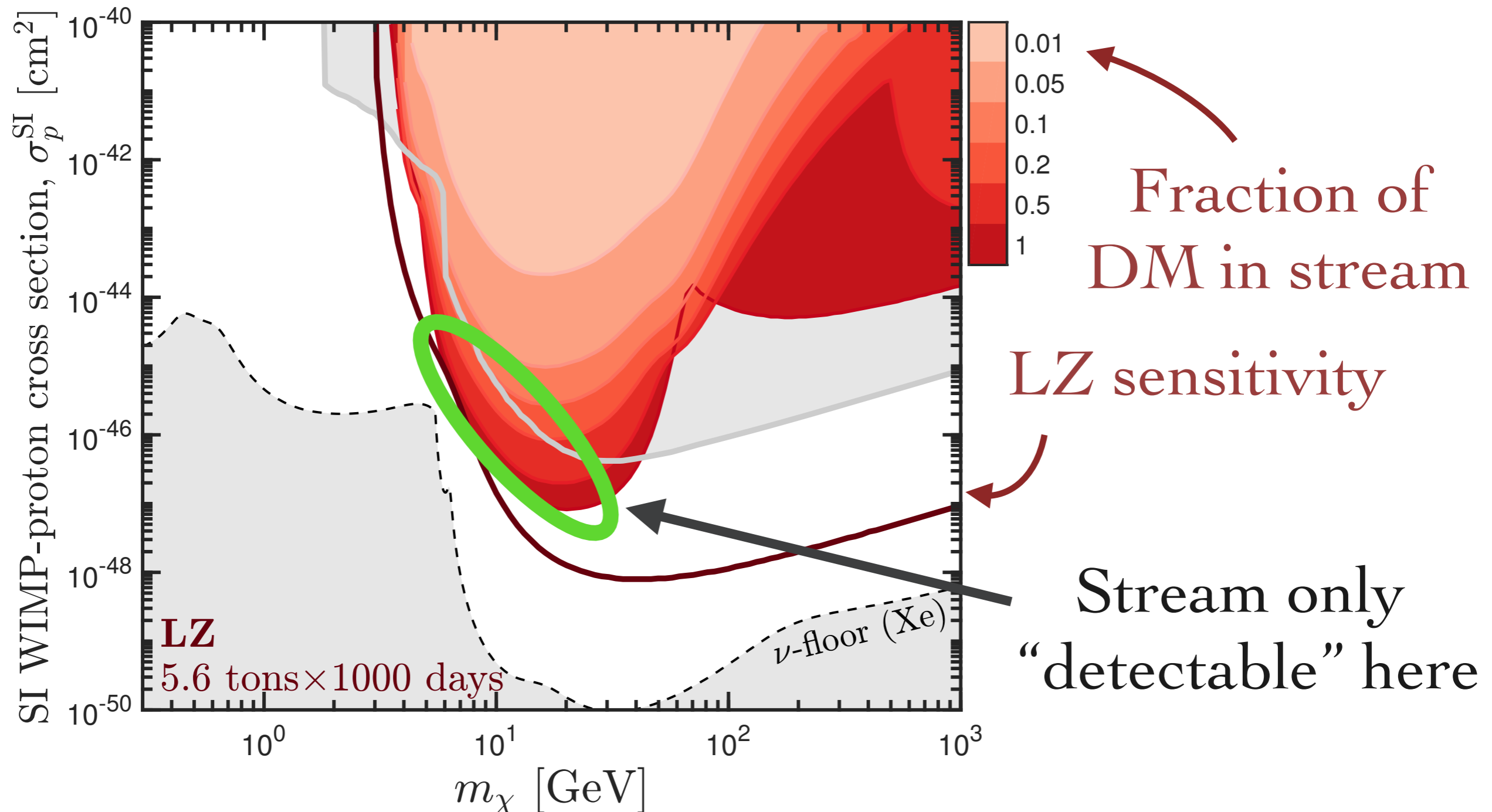


**Stream in same direction as DM wind:
No change to annual modulation, but an
enhancement of the dipole anisotropy**



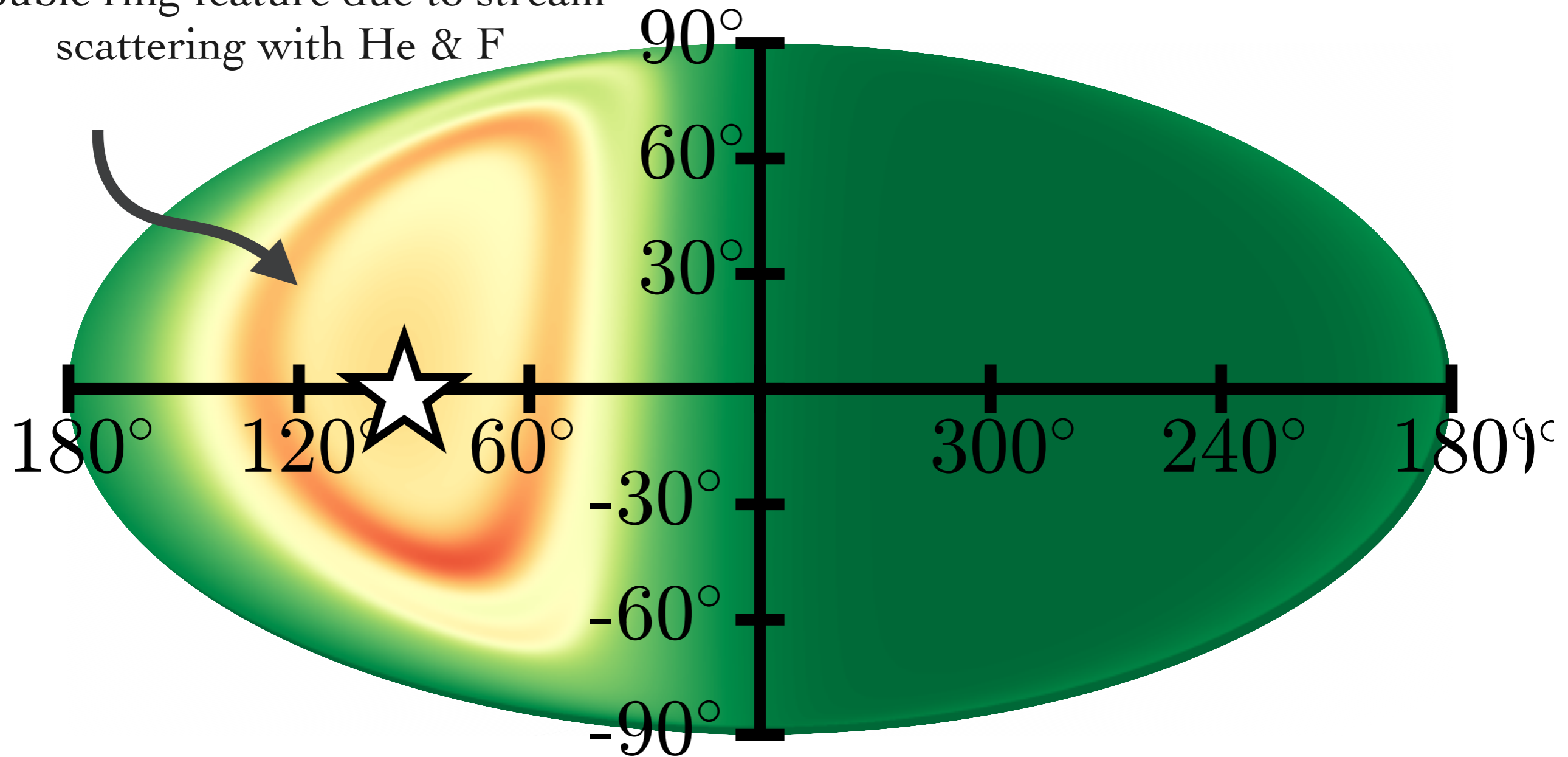
S1 in LZ

Red regions: range of WIMP masses and couplings for which the stream can be distinguished from the halo in LZ at 3 sigma



Signal of S1 in directional detector

Double ring feature due to stream scattering with He & F



Velocity distribution = 90% Halo + 10% S1

S1 in CYGNUS

Green regions: range of WIMP models for which the stream can be distinguished from the halo in CYGNUS at 3 sigma

