Probing dark matter streams with direct detection experiments

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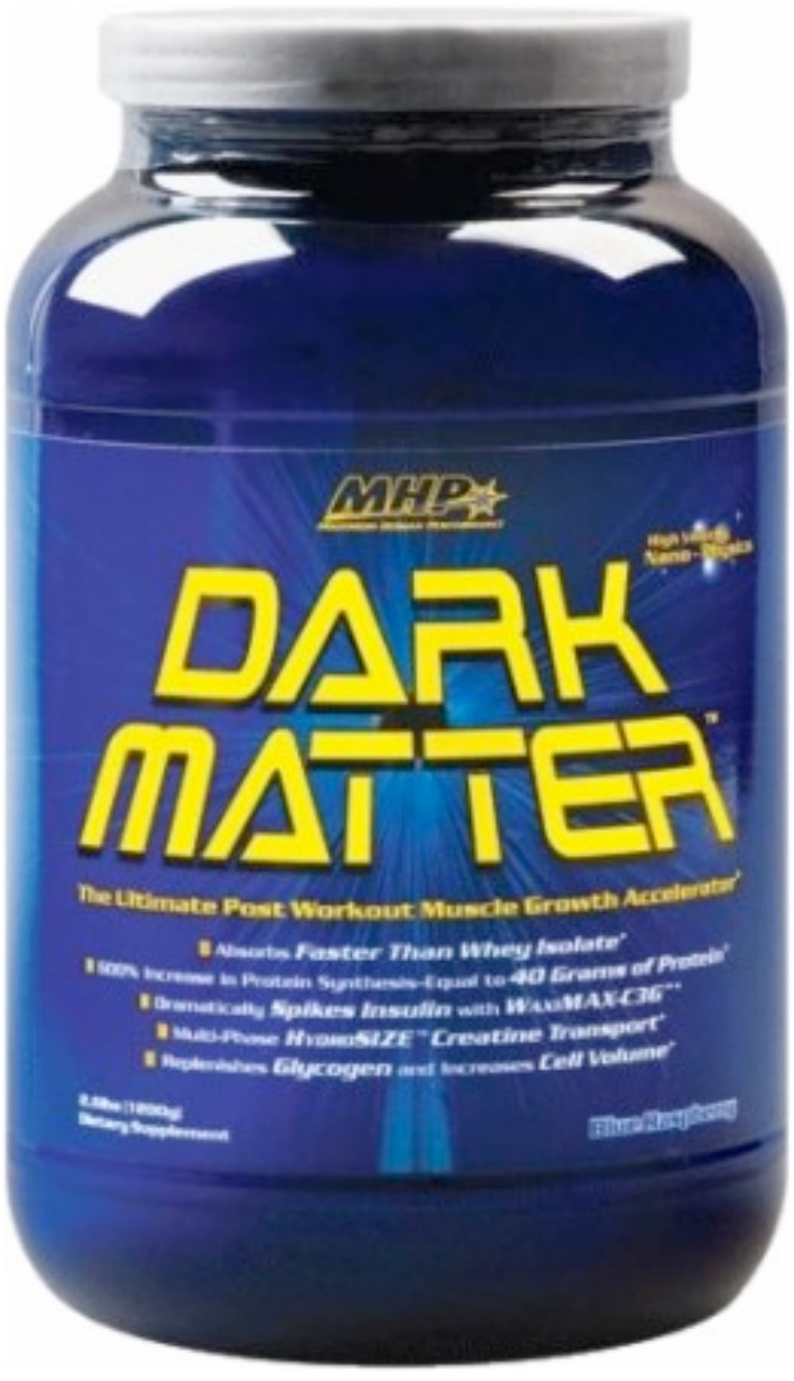
Have we found Dark Matter ?



2.6 Lbs. **Blue Raspberry**

Serving Size: 2 Scoops (60.7 g)
Servings Per Container: 20

Amount Per Serving		% Daily Value
Calories	240	
Calories From Fat	0 g	
Total Fat	0 g	0%
Saturated Fat	0 g	0%
Trans Fat	0 g	0%
Cholesterol	0 g	0%
Total Carbohydrate	48 g	16%
Sugars	10 g	†
Dietary Fiber	0 g	0%
Protein	12 g	20%
Dark Matter™ Proprietary Blend (Patent Pending)	60 g	†

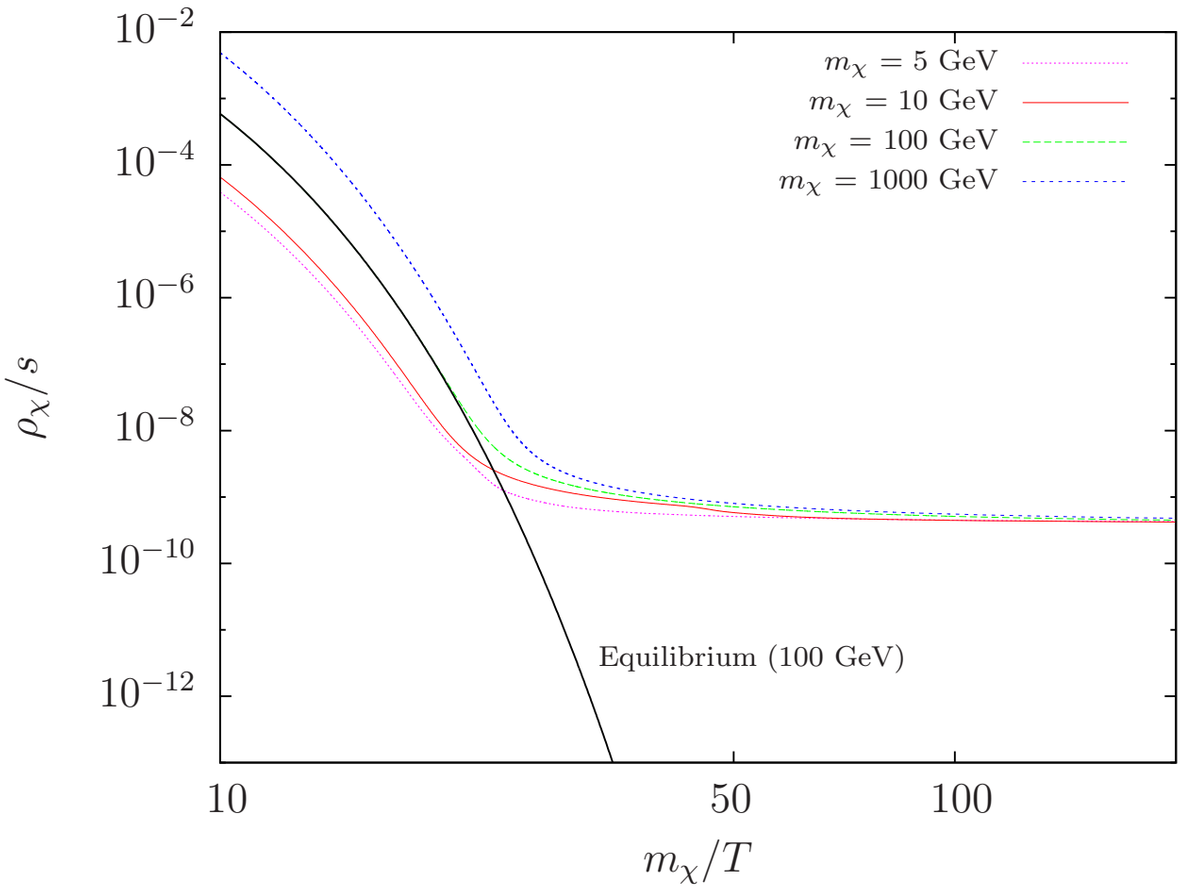
Let's suppose the Universe is not made up of Blue Raspberry . . .

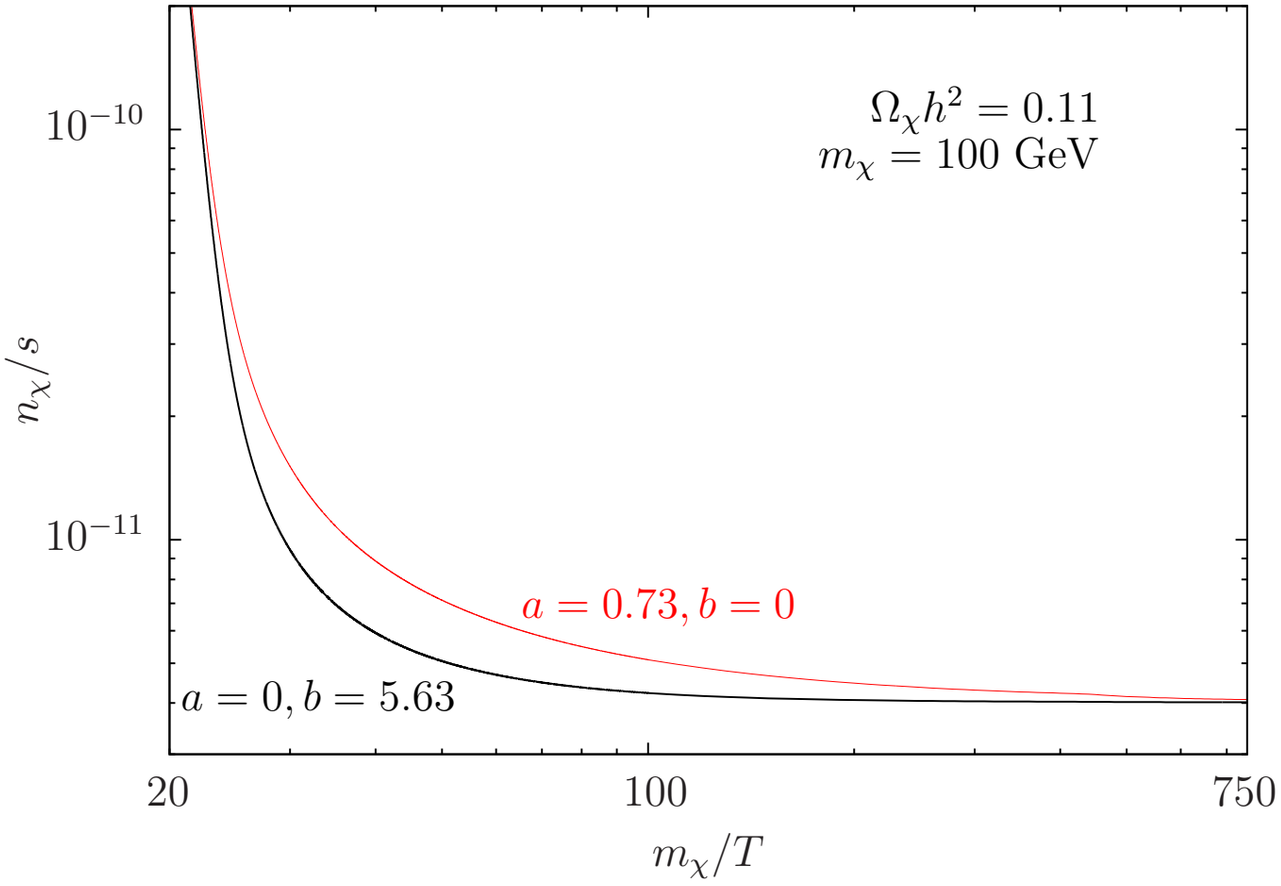
Motivation for Weakly Interacting Massive Particles

Were suggested to solve problems in particle physics unrelated to dark matter.

Have weak interactions in addition to gravity.

Theoretical motivation





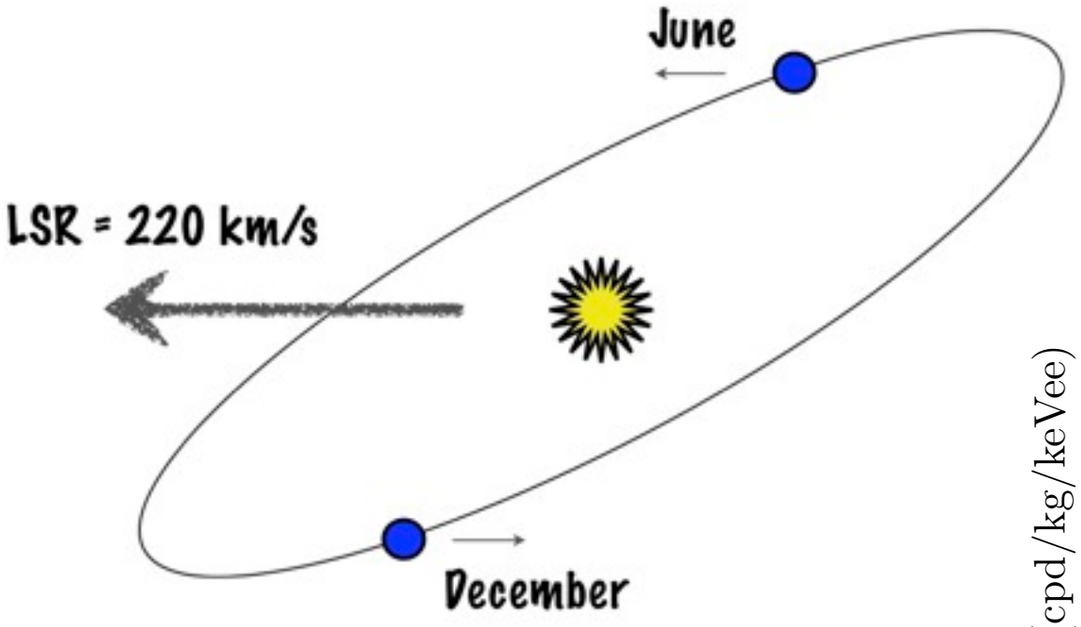
$$\sigma v \approx a + bv^2 + \cdots$$

$a \approx 2.2 \times 10^{-26}$ cm^3/s, $b = 0$ $\qquad$ $b \approx 17 \times 10^{-26}$ cm^3/s, $a = 0$

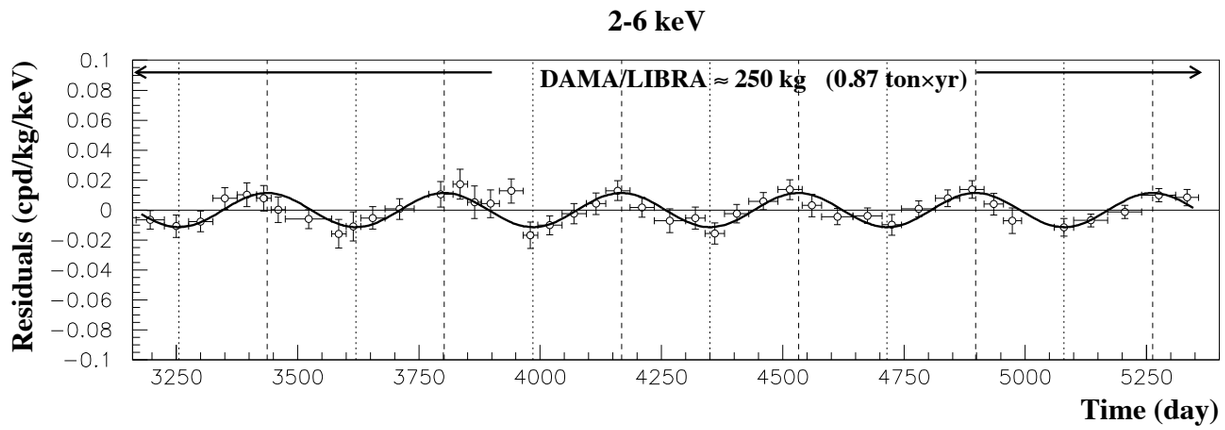
A.N., Tao Han and Zhen Liu, in prep.

Exciting results from experiments

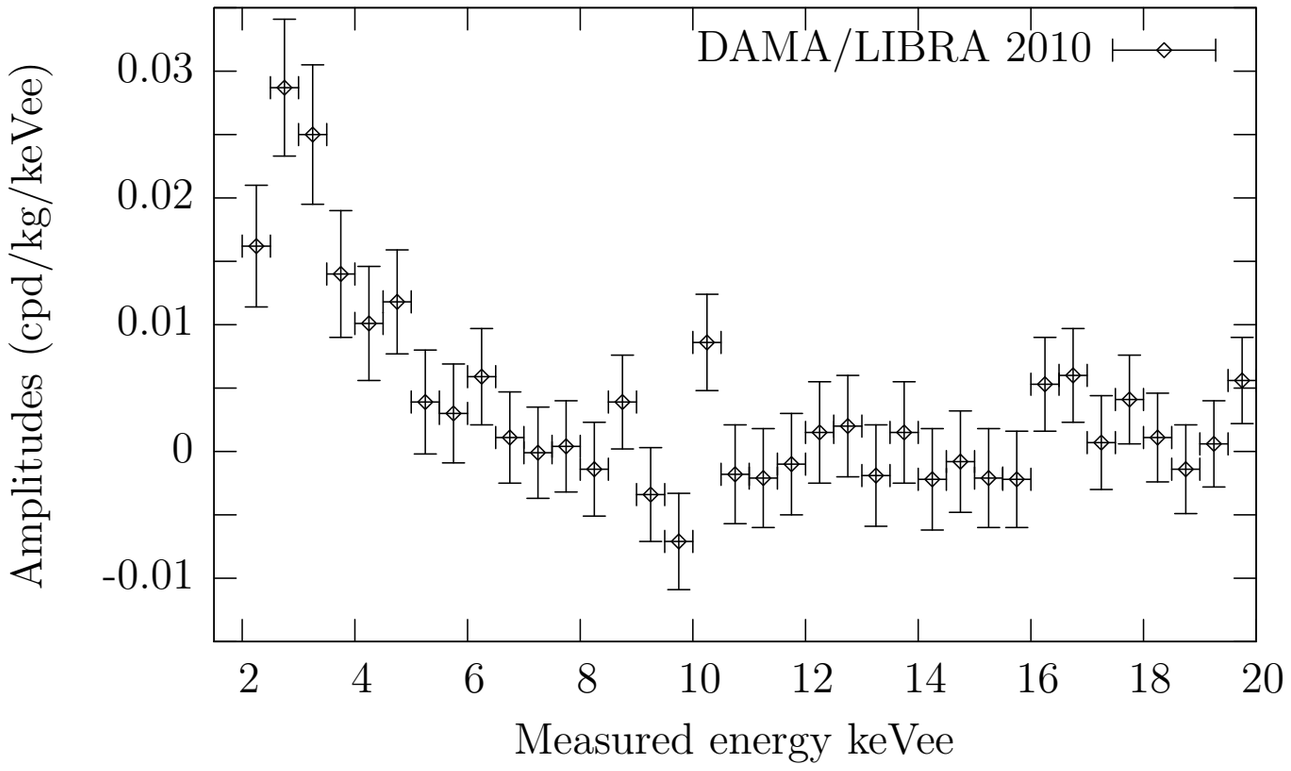
See talk by P. Belli



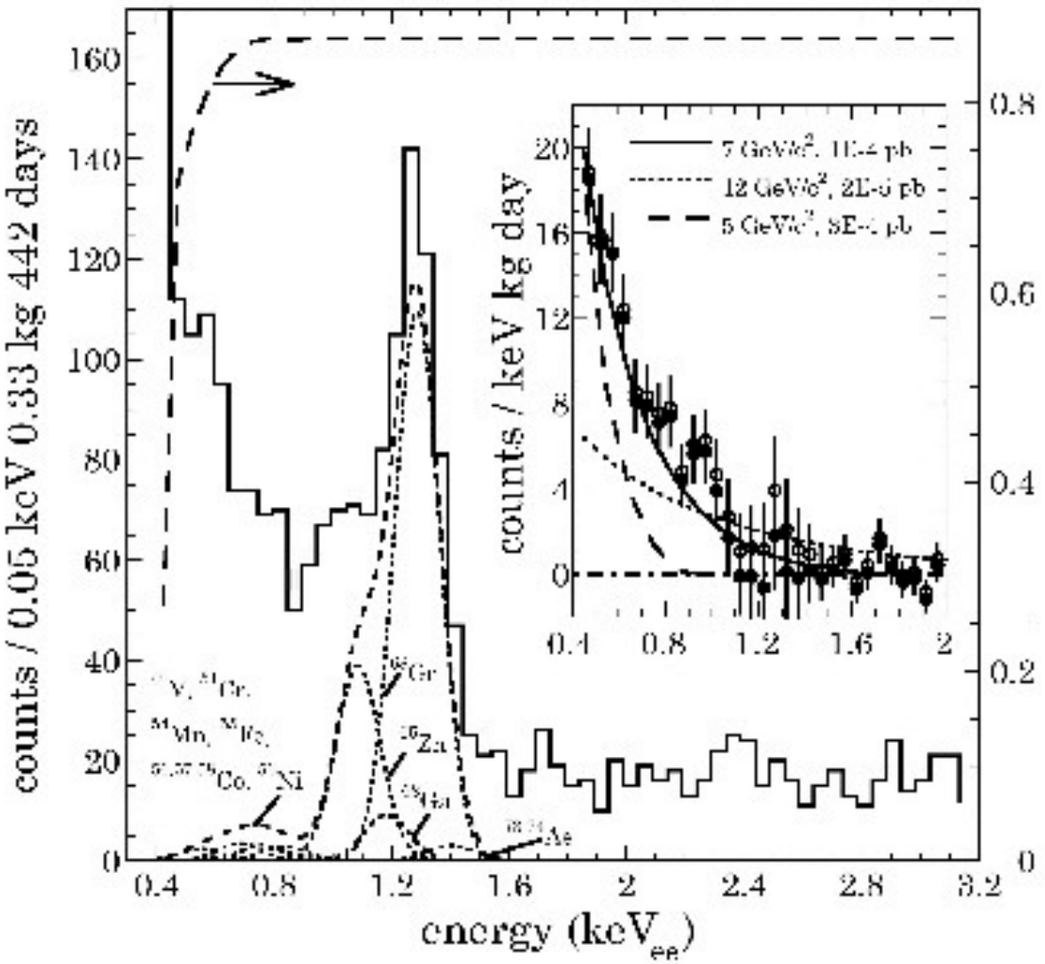
Drukier et al. '86; Freese et al. '88

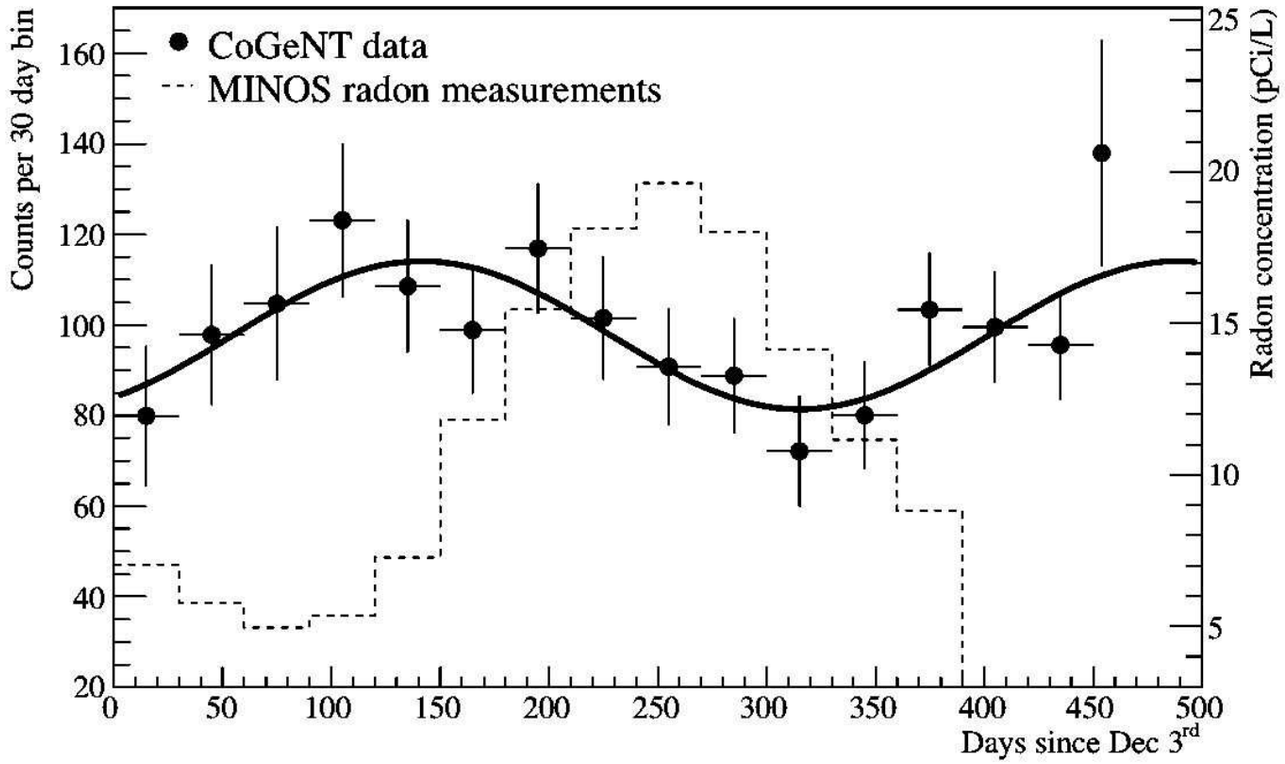


Bernabei et al, for DAMA 2010



Exciting results from experiments

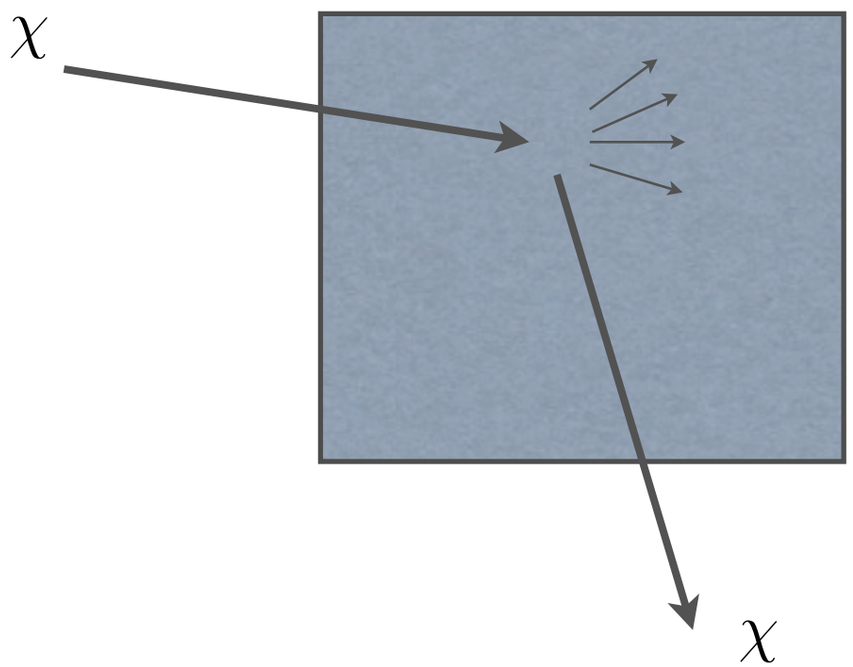




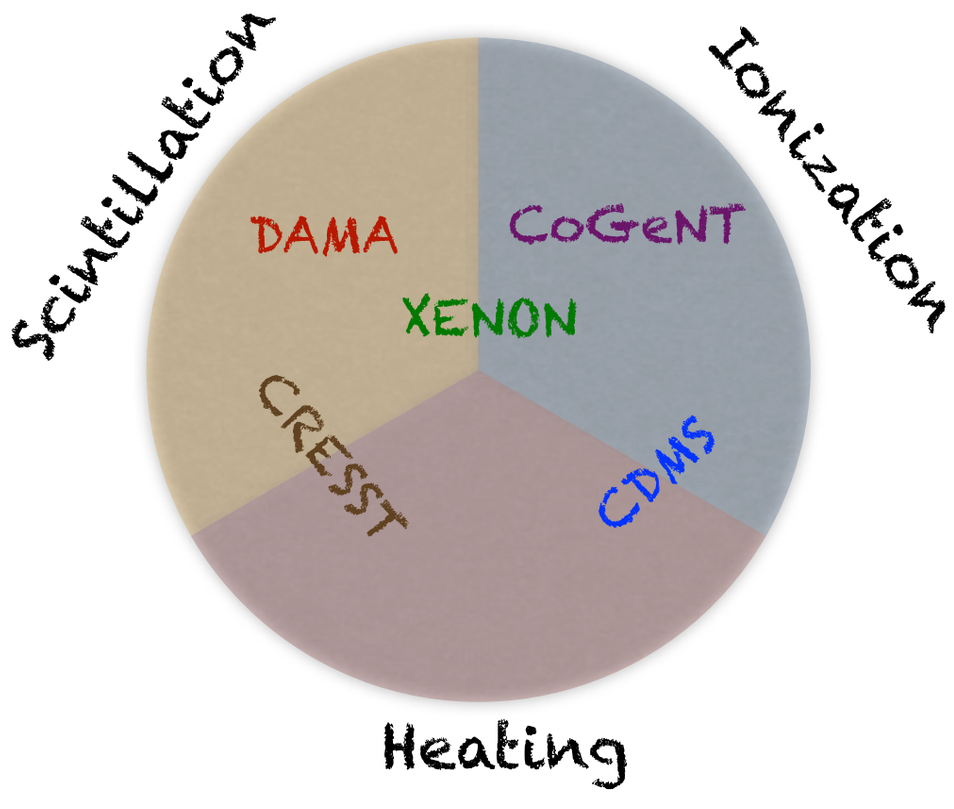
Aalseth et al. for CoGeNT 2011, 2012

However: Not seen by other d.d. expts e.g. XENON-10

WIMP-nucleus scattering



Goodman & Witten 1985
Griest 1988
Engel 1991



# of scatterings / time = $n_\chi \, \sigma \, v$

$$= \quad n_\chi \; [dQ \; (d\sigma/dQ)] \; [dv \; v \, f(v)]$$

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$$= \; n_\chi \; [dQ \; (d\sigma/dQ)] \; [dv \; v f(v)]$$

rate sensitive to the distribution of DM velocities

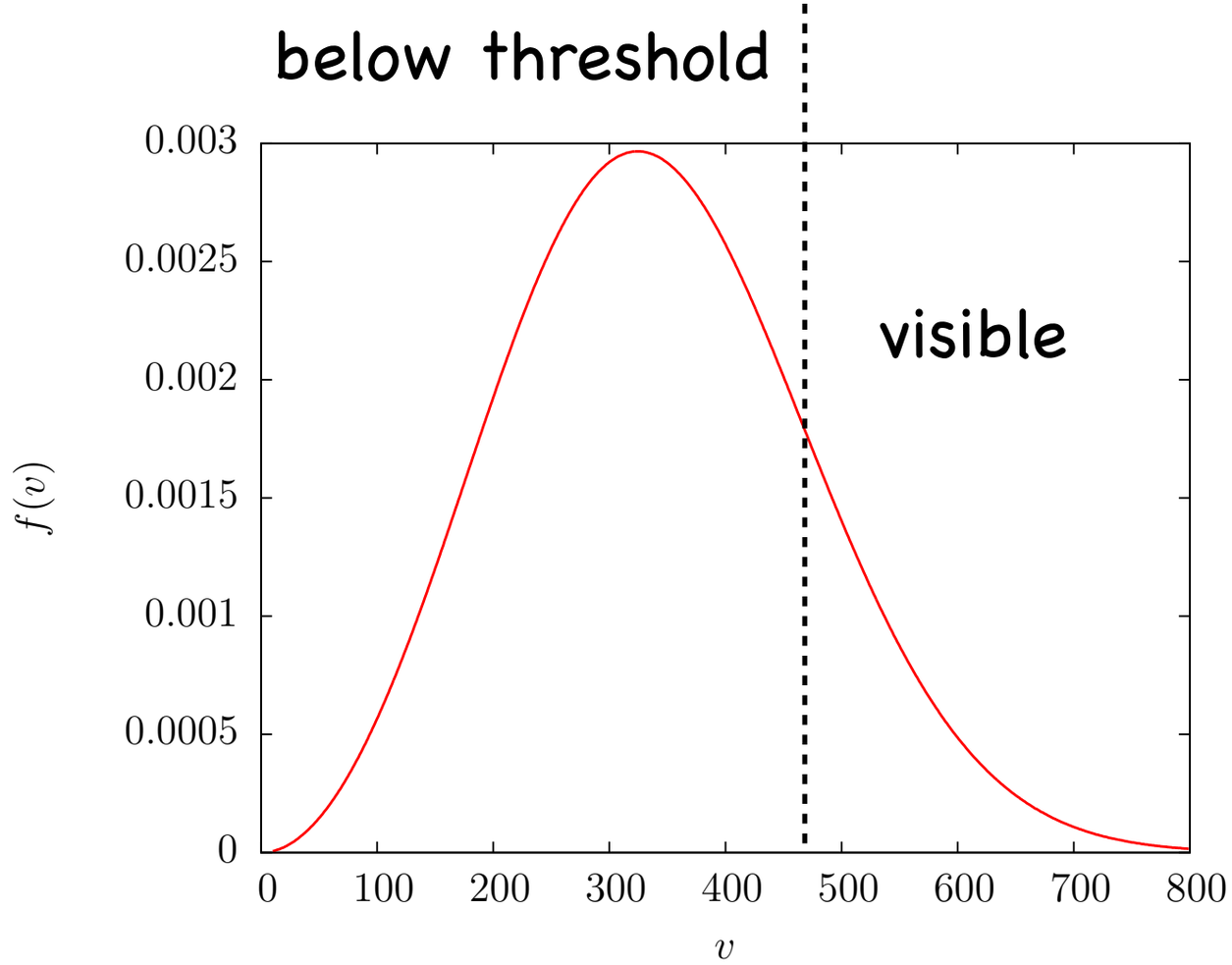
Detectors have a non-zero energy threshold

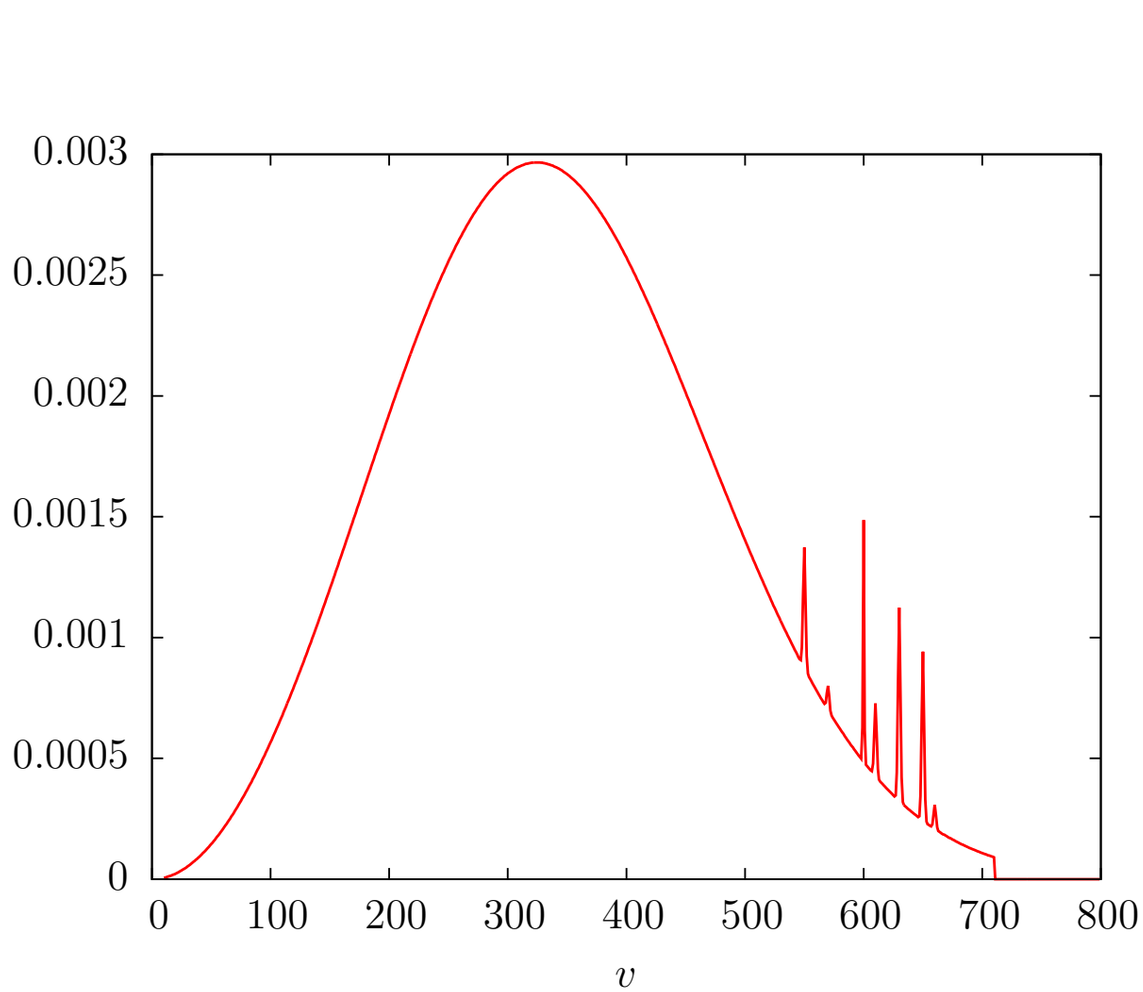
=> Fast moving particles are easier to detect at low energies.

f(v) in the earth frame.

For DAMA, an 8 GeV WIMP requires v > 480 km/s

for Na quenching factor 0.3, v_0 = 220 km/s





Non-thermal features are expected from:

1. Debris flows from breakup of many halos.

See talk by M. Lisanti

Non-thermal features are expected from:

2. Late infall of DM onto the virialized halo.

- The turnaround or mass-collecting radius of the Milky Way > 1 Mpc.

i.e. There is a lot of DM outside the virial radius.

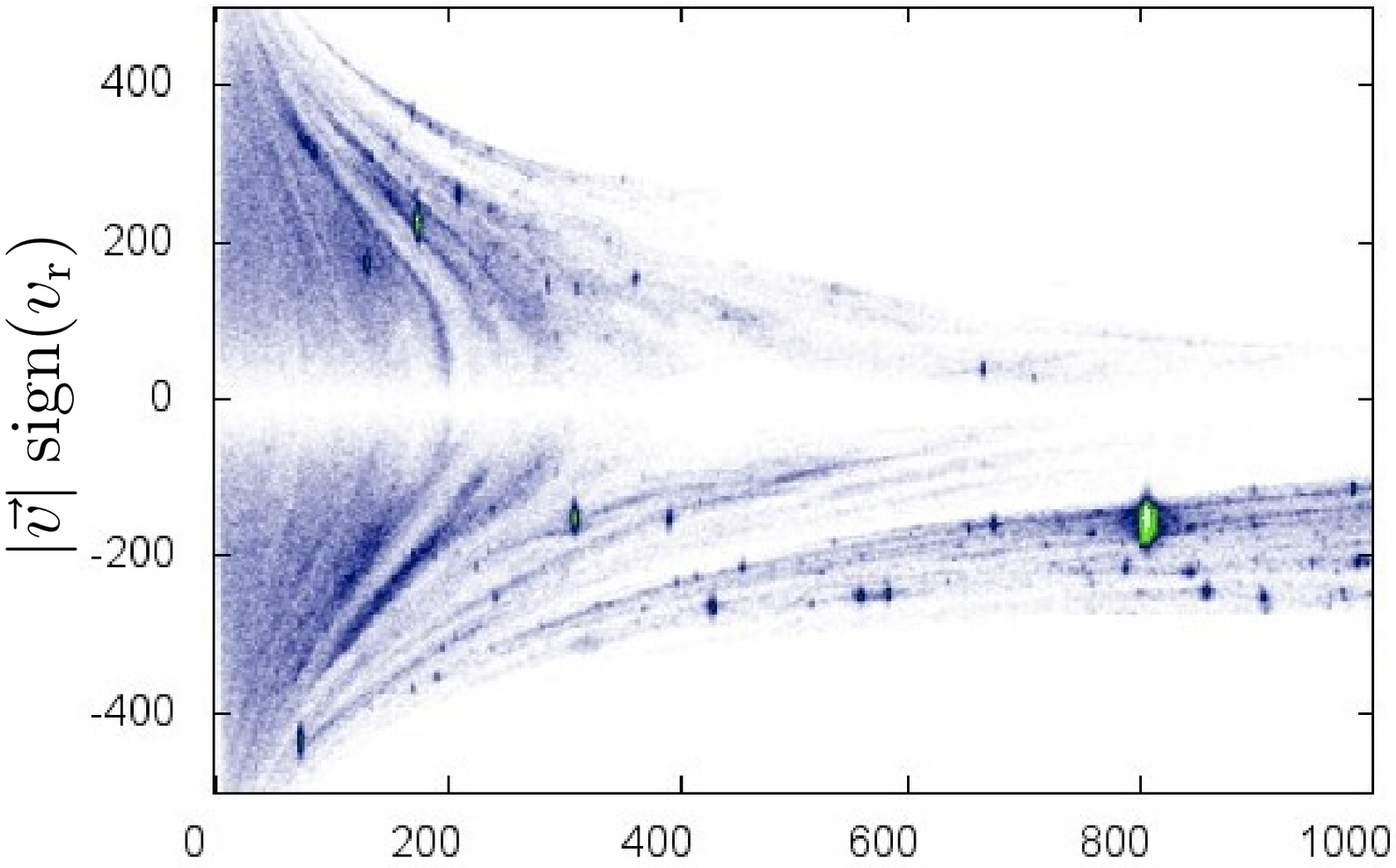
- DM occupying the outer regions of phase space have fallen in only a few times over the age of the Galaxy.

- High velocity particles don't spend much time in the inner regions where substructure is present.

ADMX & fine structure - see talk by D. Tanner

Non-thermal features are expected from:

2. Late infall of DM onto the virialized halo.



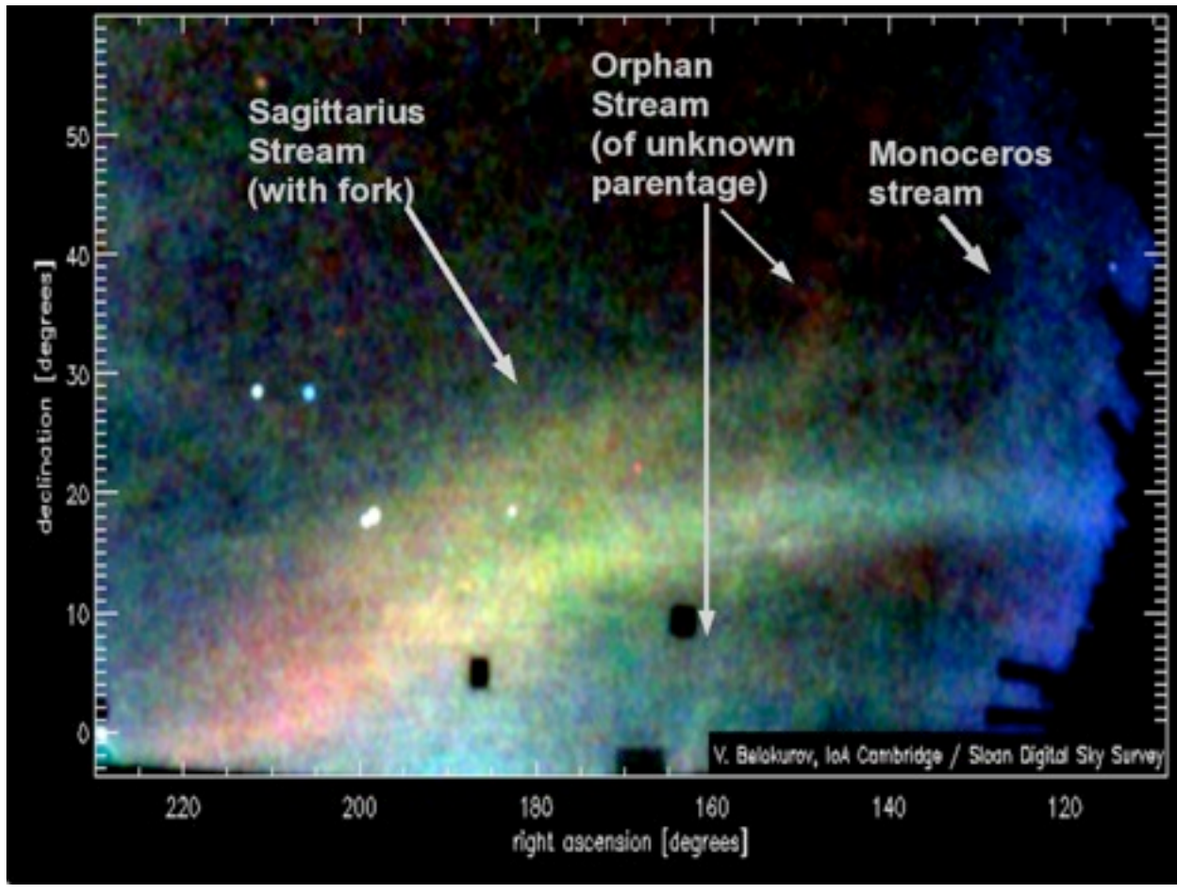
Simulation by
Dolag, Dolgov, Tkachev 2012

Consistent with present DAMA data.
Testable with more data and lower energy threshold.

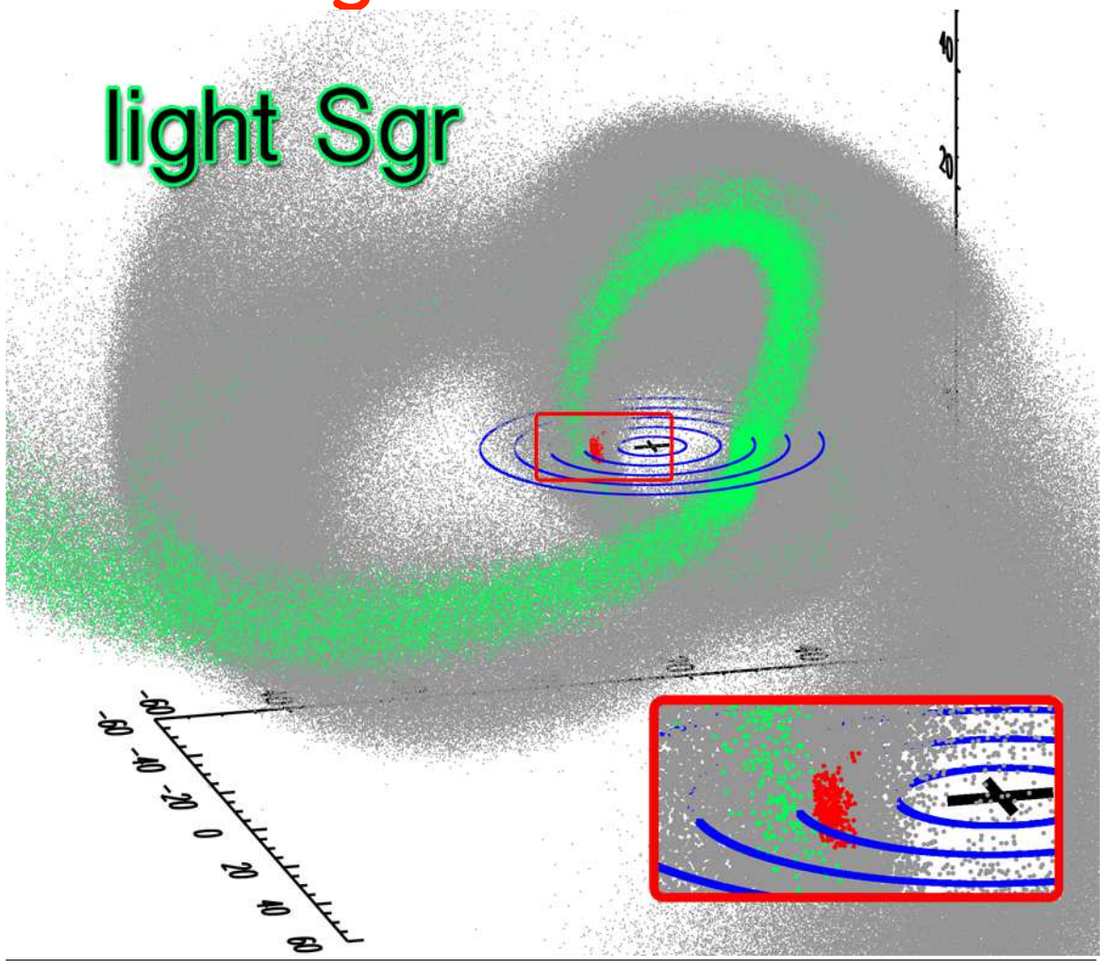
A.N. 2010, 2011.

Non-thermal features are expected from:

3. Tidal disruption of dwarf galaxies.



"Field of streams"
Belokurov, for SDSS 2006



Sagittarius simulation by
Purcell, Zentner & Wang 2012

Lynden-Bell et al. '95; Ibata et al '94; Newberg et al. '02;
Majewski et al. '03; Freese et al. '04;

Motivation to consider the Sag stream

See for e.g. Belokurov et al. Jan 2013

Ongoing major merger.
Observations by Sloan (stripe 82).
Multi-band photometry possible and radial velocities known.

Main sequence turn-off stars help define the plane of the Sag debris.
Blue Horizontal Branch stars provide distance measurements
Bright red giants show us the leading and trailing tales.

Accurate simulations have been performed to study the grav. potential of the Milky Way and the motion of stars/DM in the Sagittarius stream.

DM component much wider than the stellar component.

Looking for tidal streams with a detector:

$$f_{\rm str}(\vec{v}) = \delta\left(\vec{v} - \vec{v}_{\rm str}\right)$$

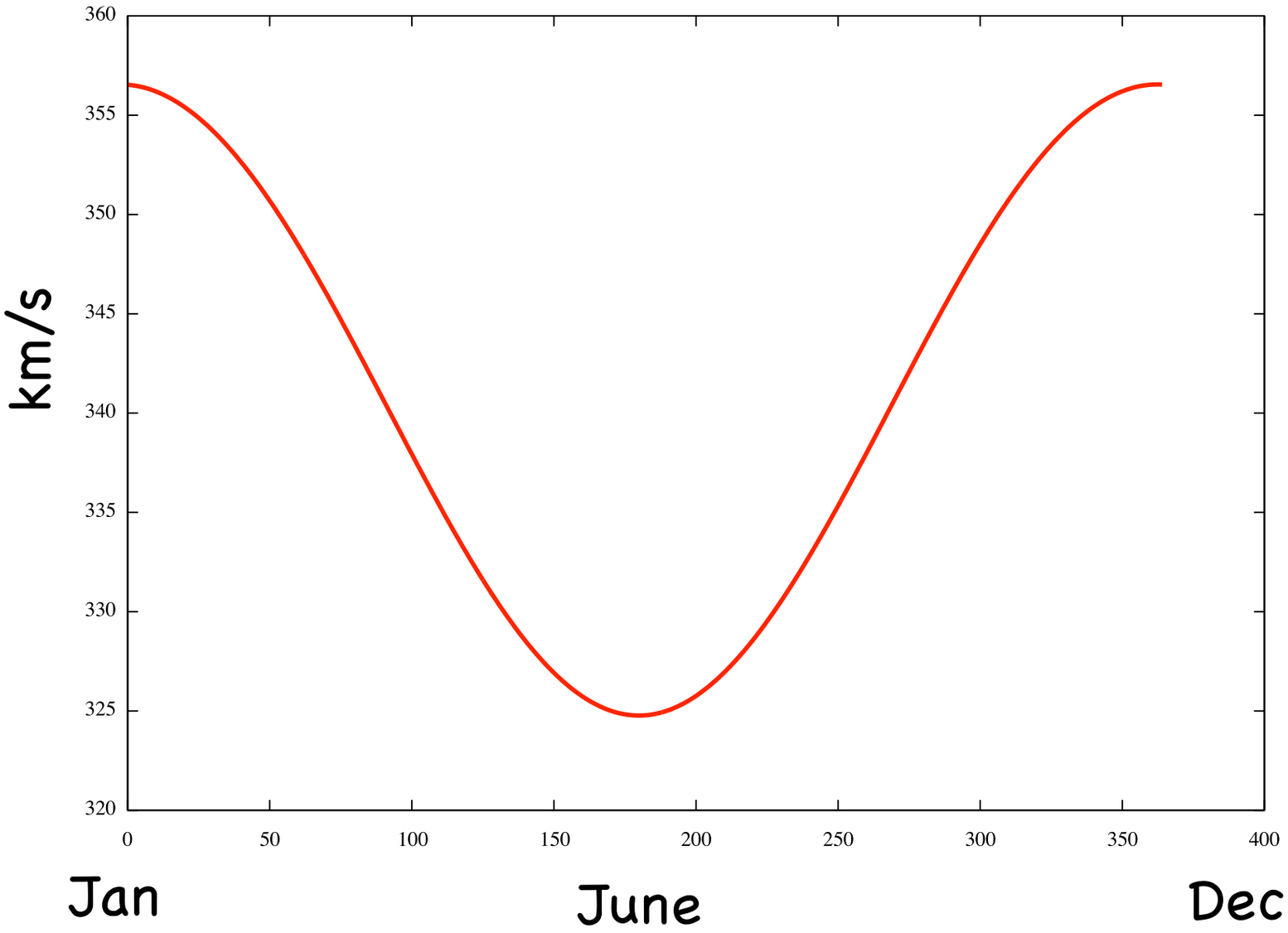
To observe recoils at Q, the DM must have a minimum velocity:

$$v_{\rm min} = \sqrt{\frac{Q m_{\rm N}}{2 m_{\rm R}^2}}$$

For a fixed velocity, the maximum energy recorded:

$$Q_{\rm max} = \frac{2 m_{\rm R}^2 v_{\rm str}^2(t)}{m_{\rm N}}$$

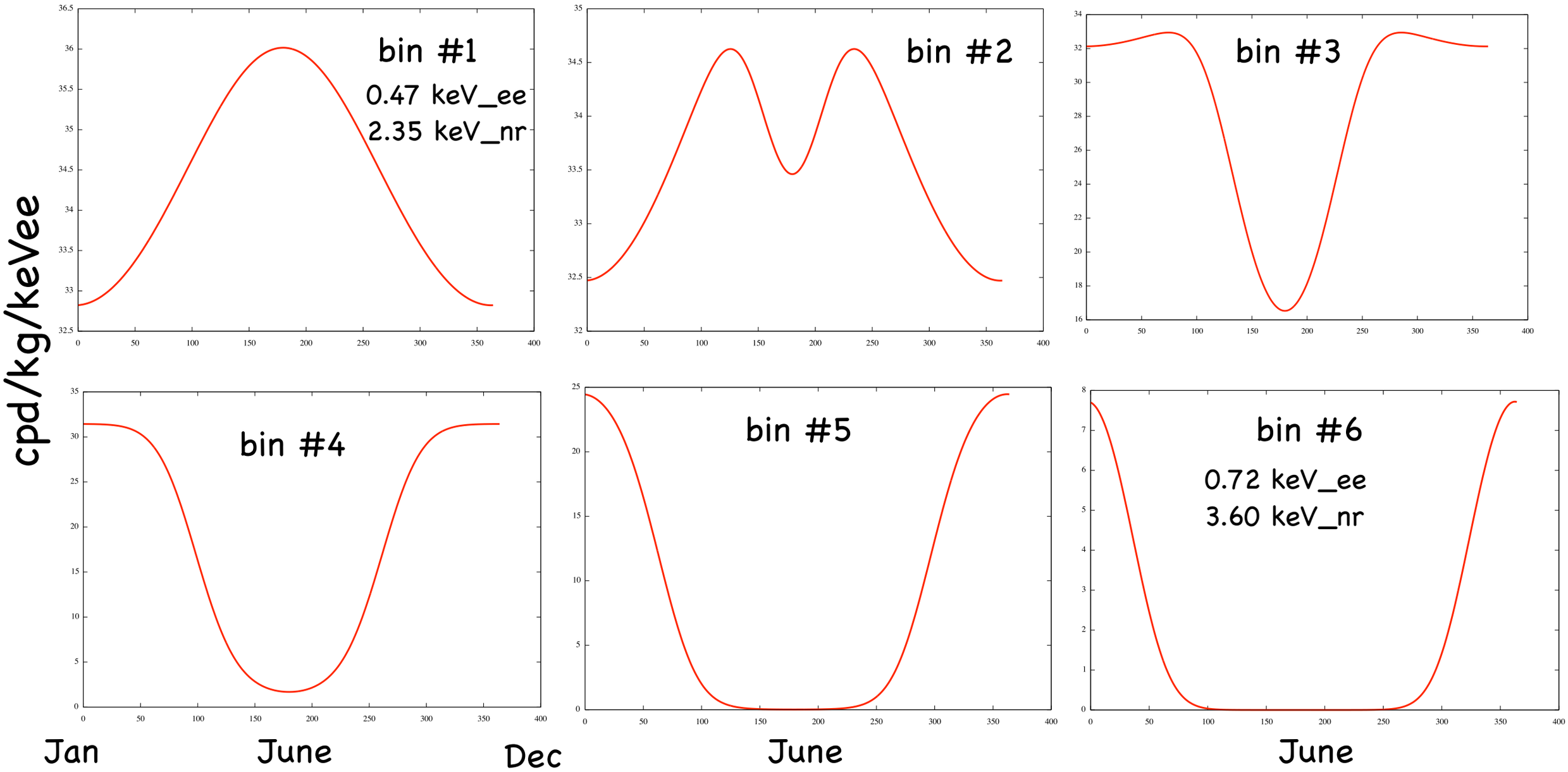
Sagittarius flow relative to the earth



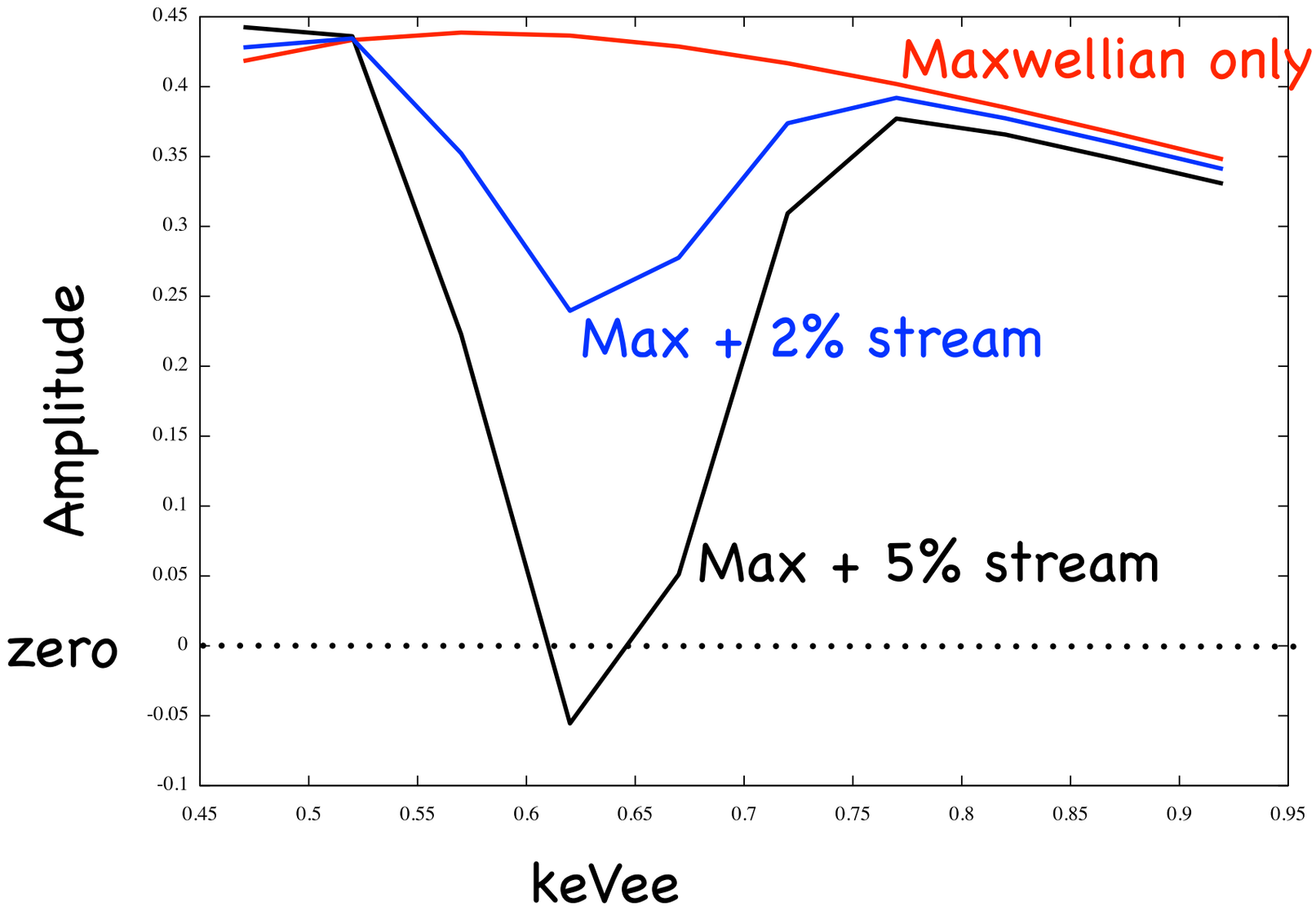
$$v_{\mathrm{str},\oplus}(t) = v_{\mathrm{str},\odot} - v_{\oplus}\left[\hat{v}_{\oplus}(t) \cdot \hat{v}_{\mathrm{str},\odot}\right]$$

Time dependence of the scattering rate

Sagittarius stream (100% contribution)
CoGeNT like experiment:
mass = 10 GeV



Annual modulation
CoGeNT-like experiment.

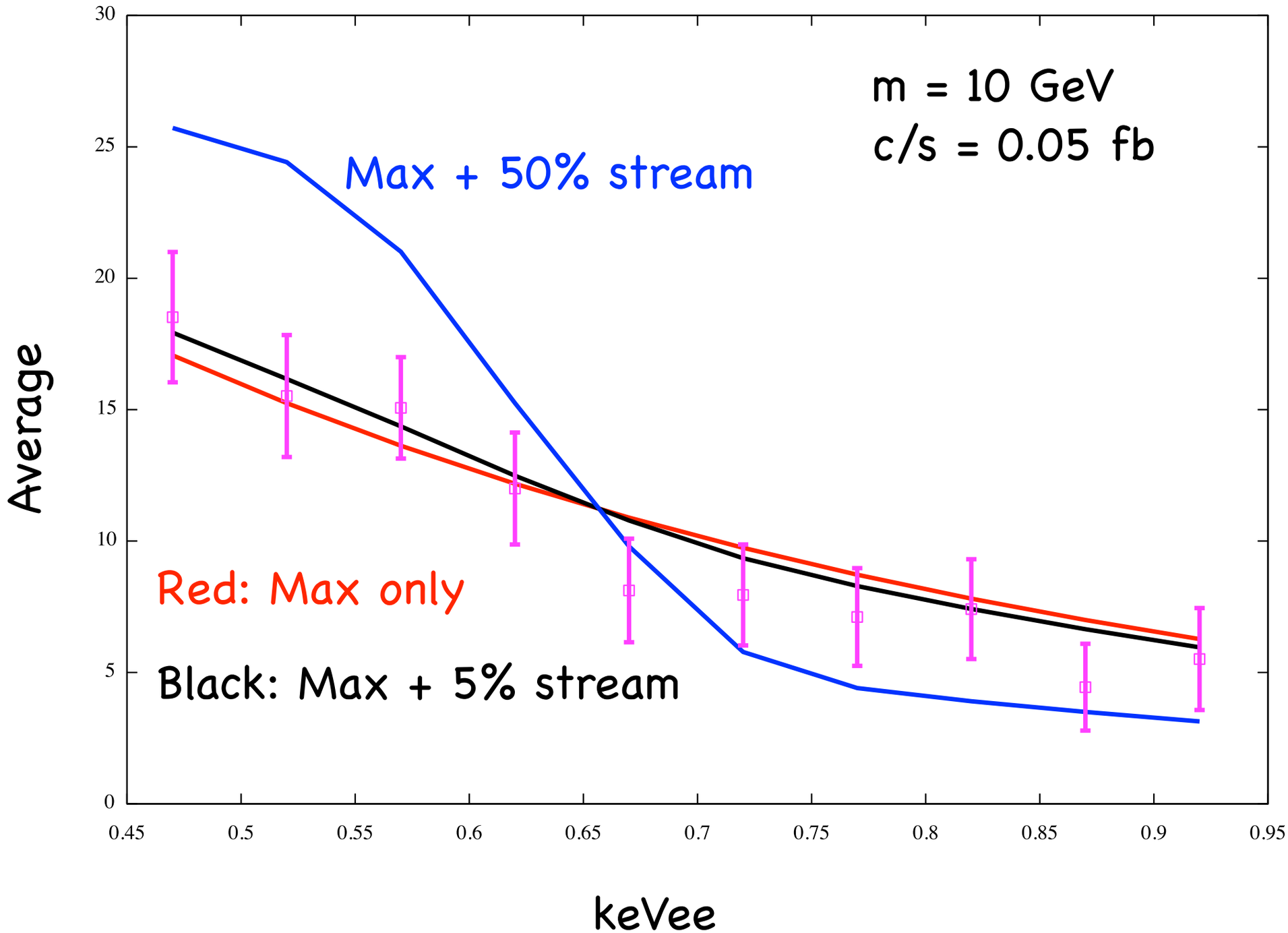


dispersion = 10 km/s

10 GeV, 0.05 fb

Energy Bin
= 0.05 keVee

Average recoil rate
CoGeNT 15 months x 0.33 kg (2011)



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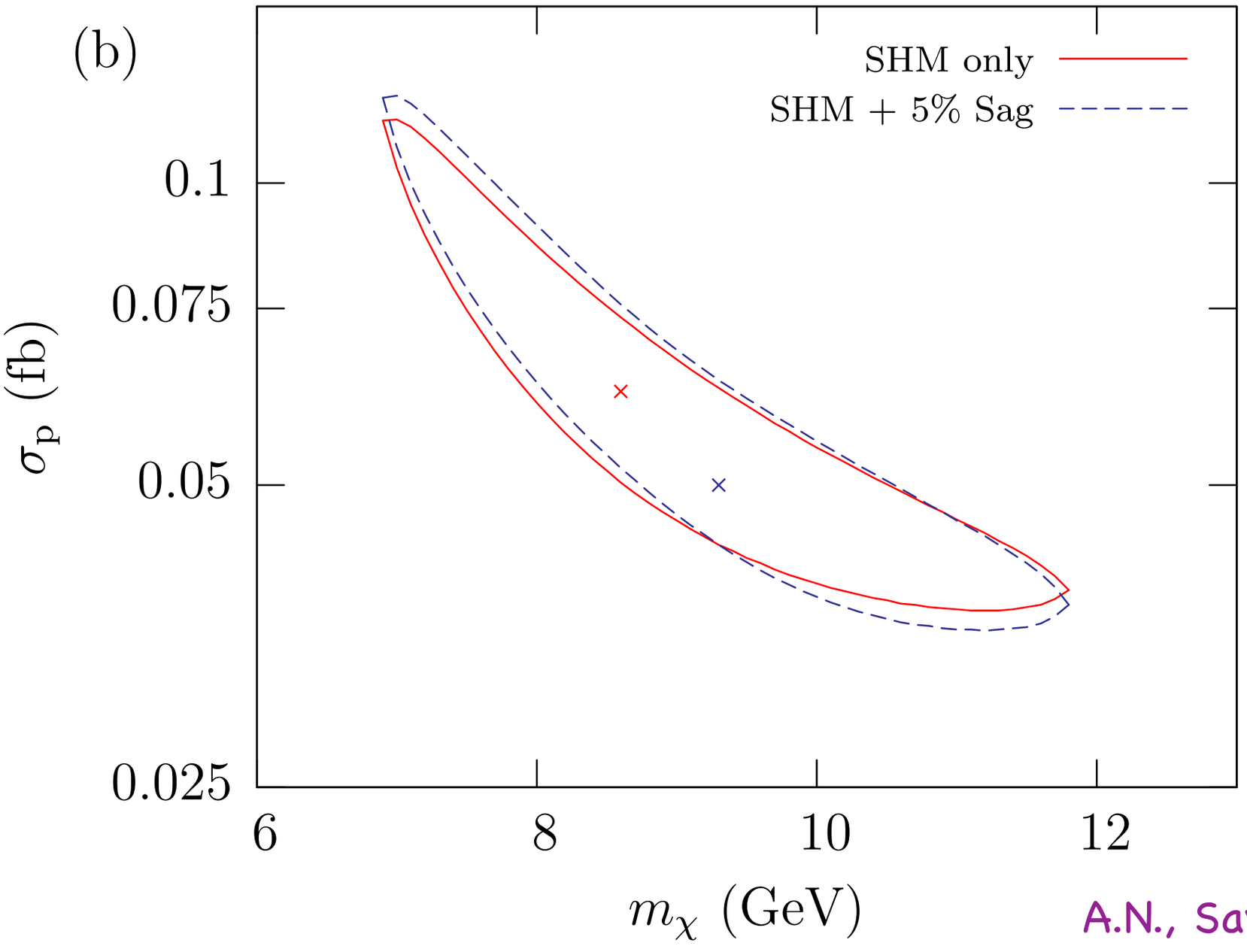


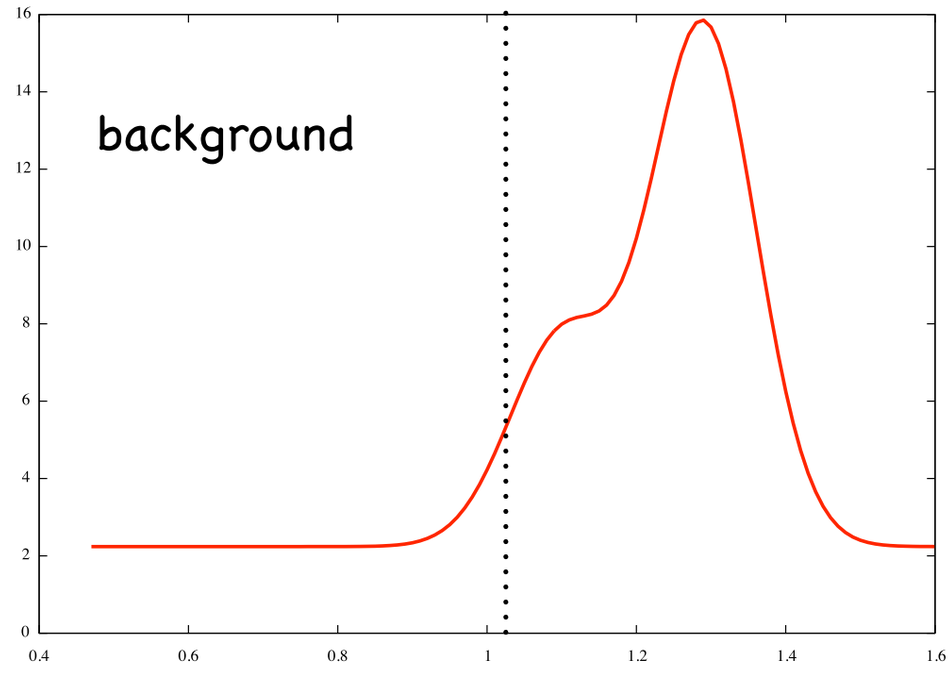
A.N., Savage, Freese, 2011

Next gen. CoGeNT C-4

- 4 large detectors
- Will increase the fiducial mass by ~ factor of 10
- Can achieve an exposure of 10 kg.year within 3 years.

Would the Sag. stream be visible with C-4 ?

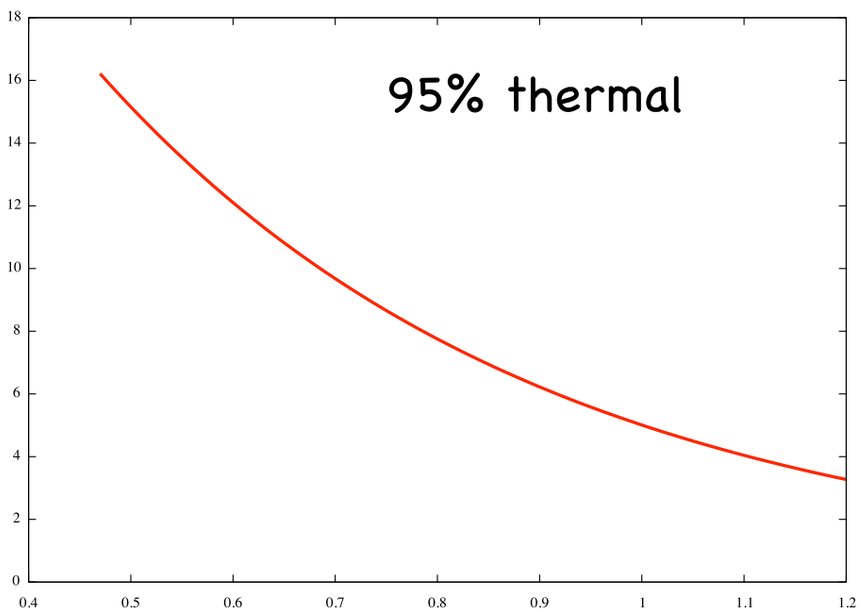
10 kg year exposure with C-4: MonteCarlo



+

mass = 10 GeV

c/s = 0.05 fb



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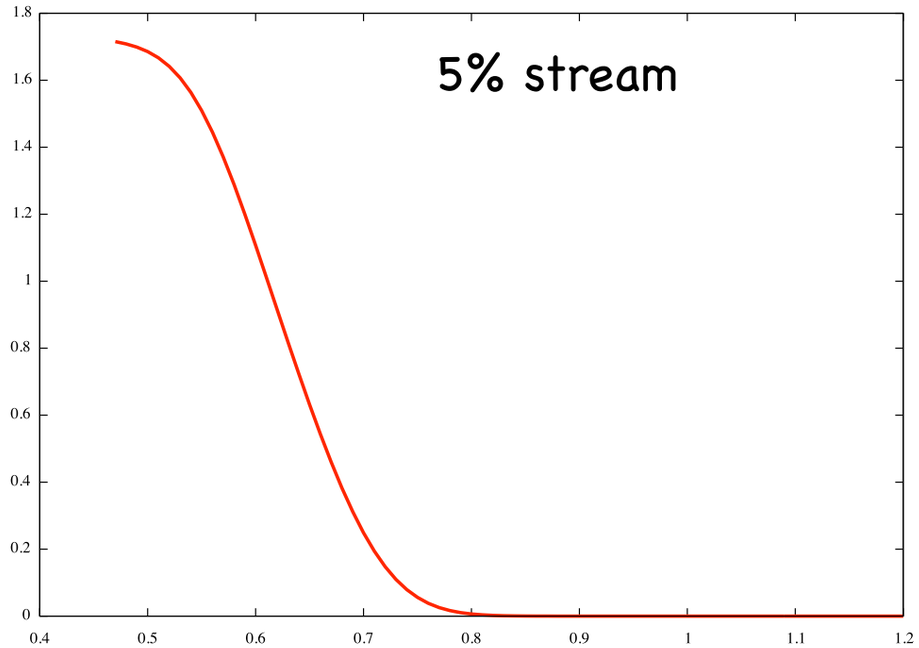
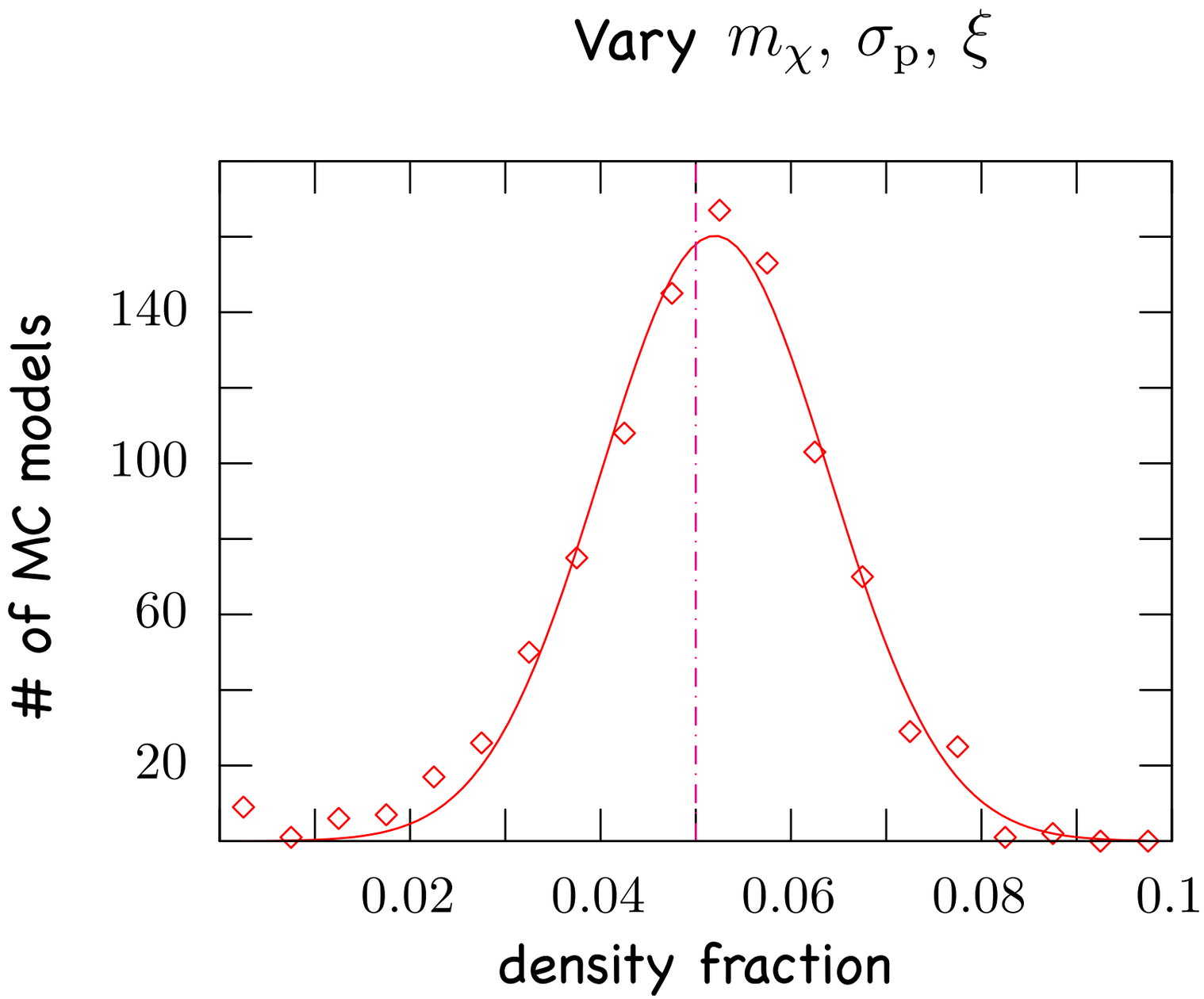
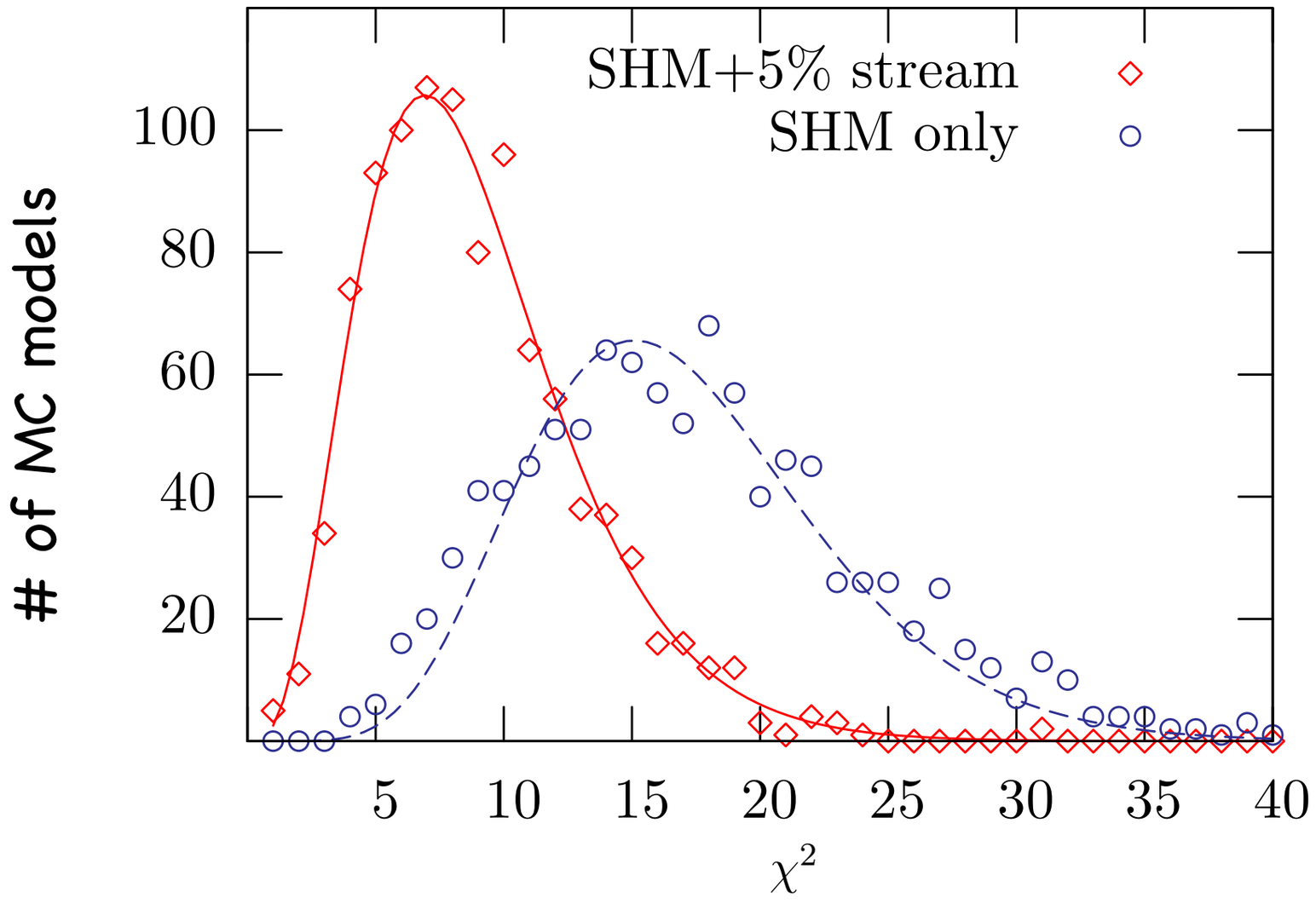


Reconstructing the stream density



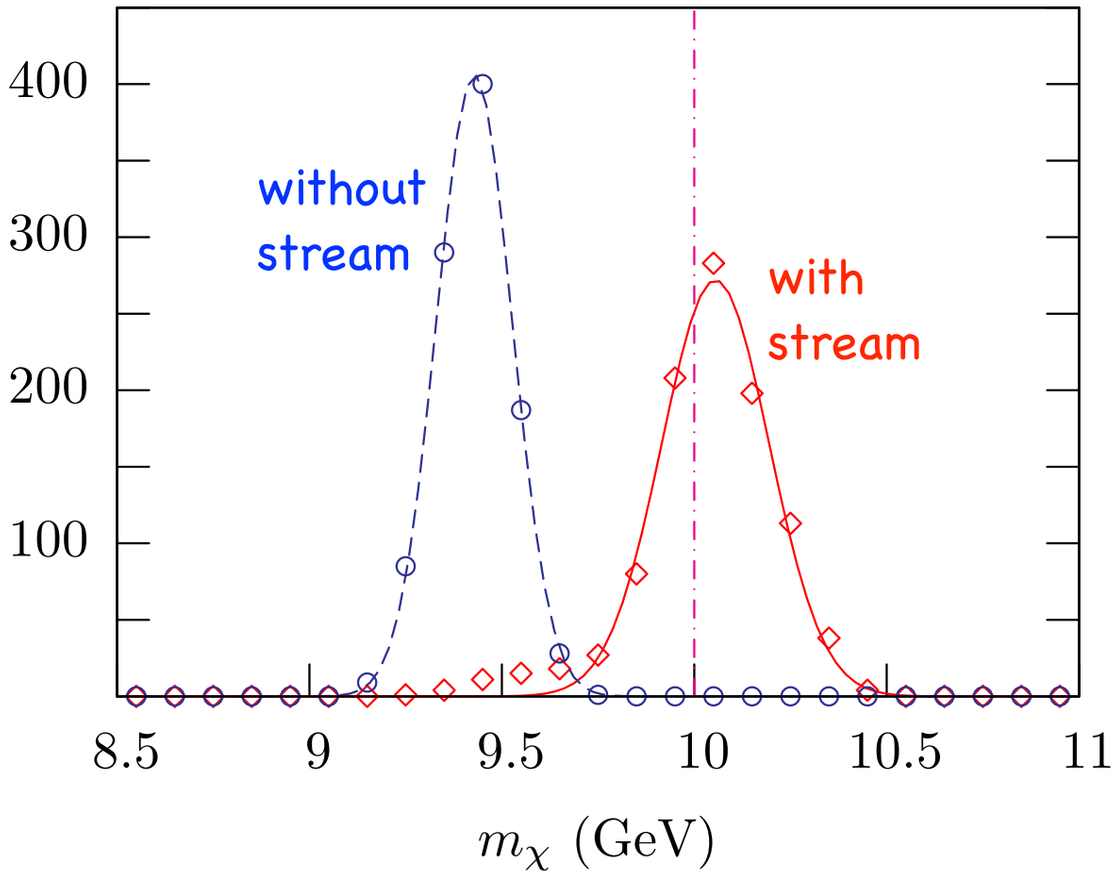
Fitting for mass and cross section

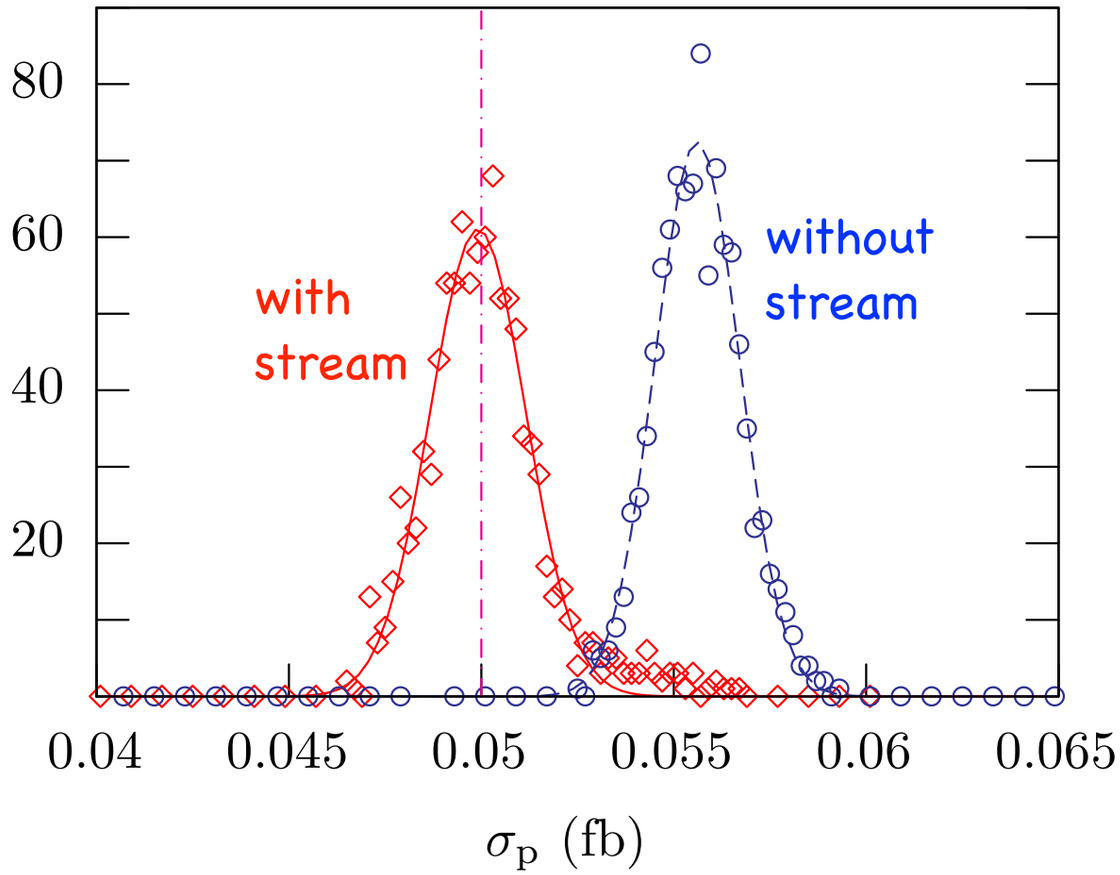


8.2/9 dof when stream is accounted for.

16.7/10 dof when stream is ignored.

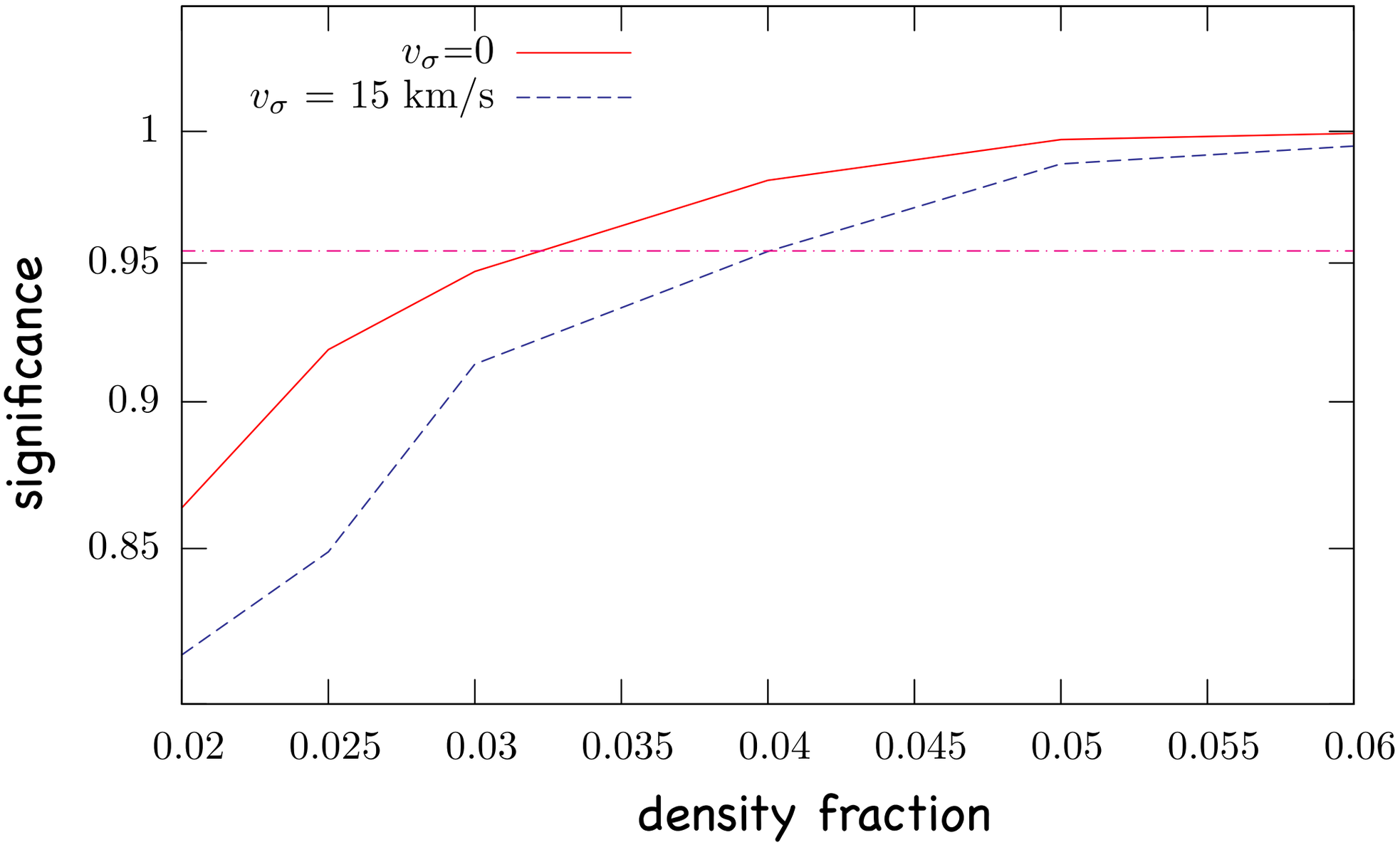
Fitting for mass and cross section





Ignoring the stream underestimates mass by 6%
and overestimates c/s by 11%

Detection significance with 10 kg year exposure



Conclusions

- Non-thermal features such as streams and debris flows should be expected due to a number of reasons.

- Direct detection experiments such as CoGeNT and DAMA are sensitive to the form of the velocity distribution.
  --> Need a low energy threshold.
  --> Good energy resolution.

- Sagittarius is a good example of a tidal stream.
  Debris from the Sag. stream may contribute a few percent to the local DM density.

- The next gen. of CoGeNT (C-4) will be sensitive to such streams with 3 years of data.