CDMS Limits and Compatibility with DAMA

(for CDMS results see PRL preprint astro-ph/0002471)

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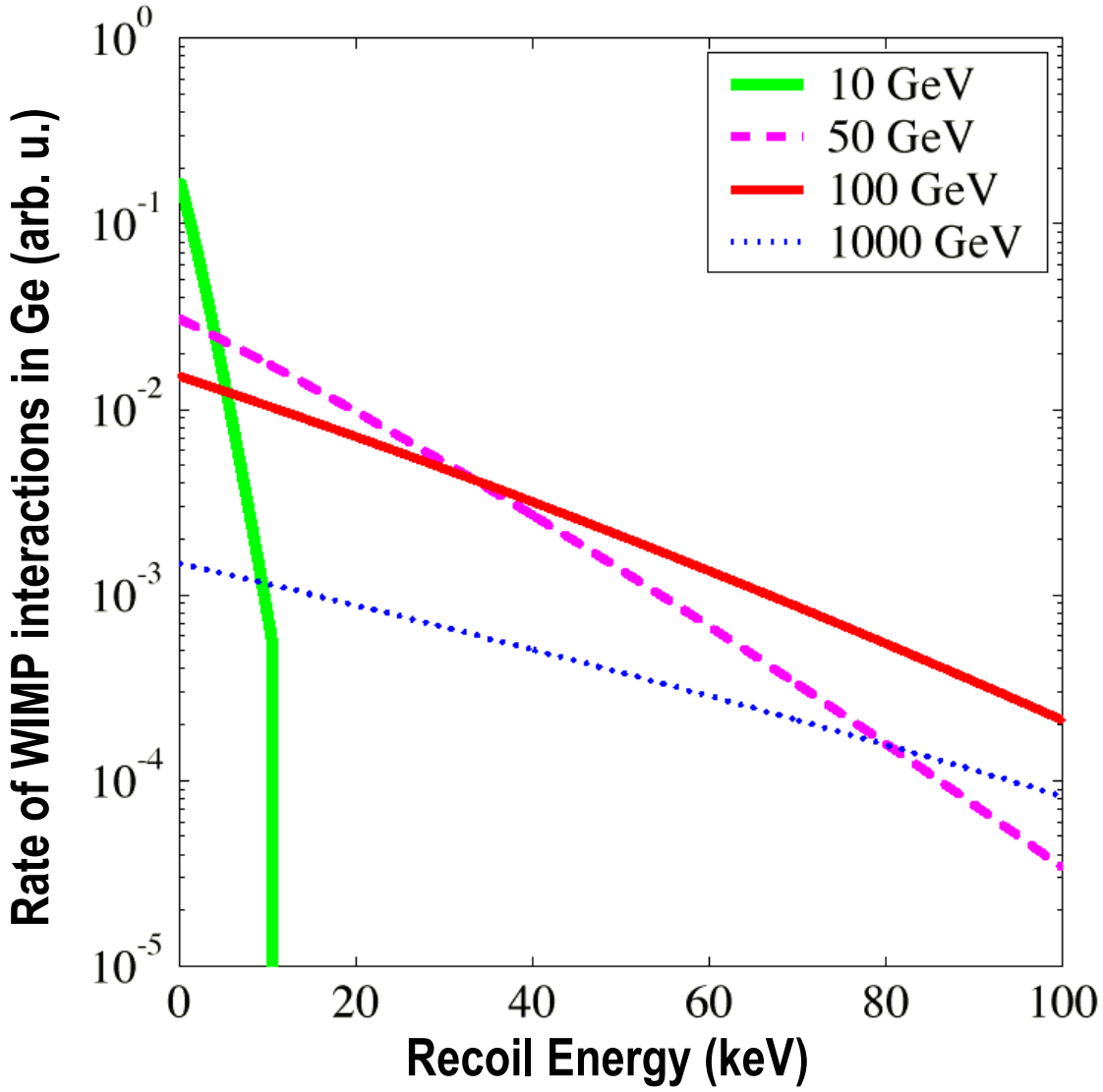
Quick Orientation to CDMS

- **C**ryogenic (detectors) **D**ark **M**atter **S**earch (for WIMPs)
- Detectors shielded in low-background environment (total trigger rate ~0.5 Hz)
- Excellent rejection of events from nearby cosmic muons or from α, β, γ radiation (13 potential WIMPs among 6.5×10^6 events for 96 live-day exposure in Ge)
- Expect neutron background (from distant cosmic muons), estimated by rate of multiple-scatters and rate of events in Silicon
- DAMA has larger background and larger expected rate, similar expected sensitivity (cf. LSND & KARMEN)

Dependence of Spectrum on (M,σ)

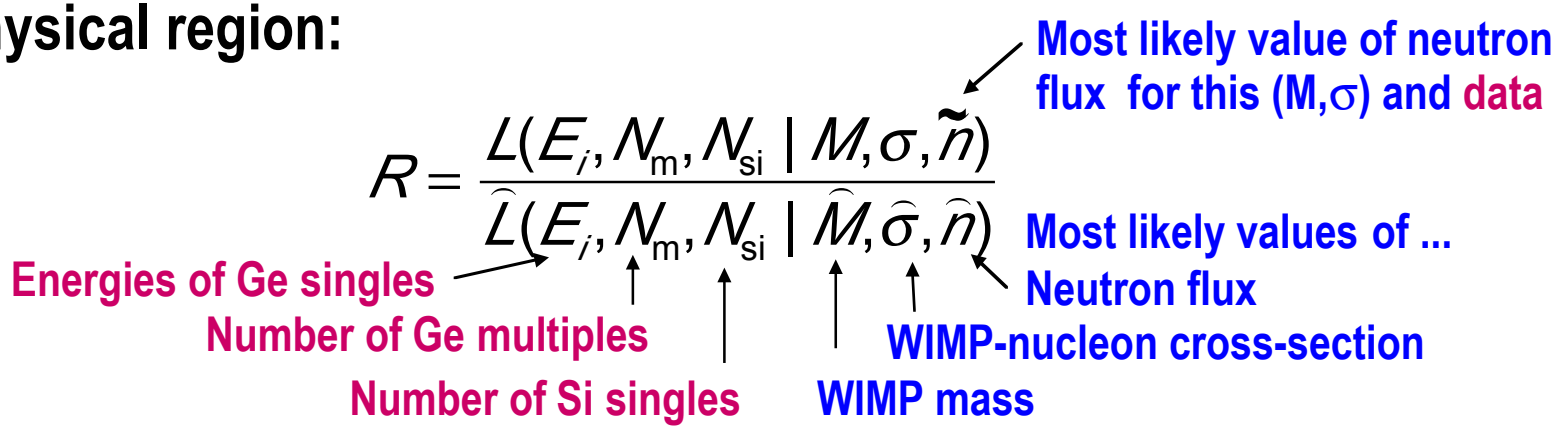


- Expected event rate scales with WIMP-nucleon cross-section σ

- Larger WIMP mass M yields harder energy spectrum (but not a huge effect for large masses)

Calculation of Allowed Region

- **Follow 'Unified Approach' of Feldman and Cousins: ordering by likelihood ratios with parameters constrained to lie inside the physical region:**

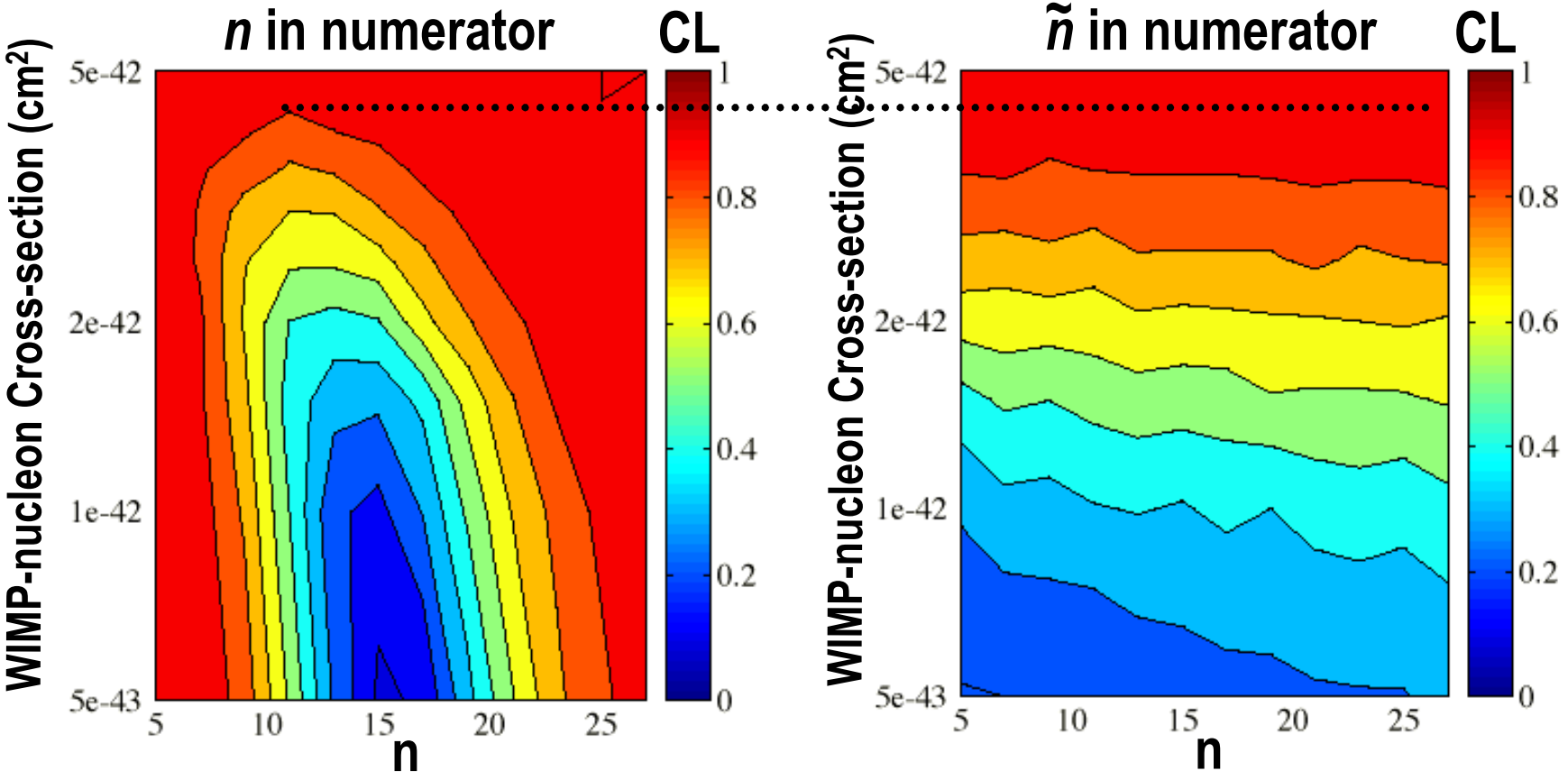


  - **Results are weakly dependent on *n*. To be conservative, project out *n*: A given point (M,σ) is excluded if $R(M,\sigma) < R_{90\%}(M,\sigma,n)$ for all n ($R_{90\%}$ determined by Monte Carlo).**
  - **Results would be overly conservative if we used**

$$R = \frac{L(E_i, N_m, N_{si} \mid M, \sigma, n)}{\hat{L}(E_i, N_m, N_{si} \mid \hat{M}, \hat{\sigma}, \hat{n})}$$

The Nuisance Parameter *n*

Slices of parameter space showing CL contours for *M* = 50 GeV



- Using most likely value of *n* in numerator of likelihood ratio *R* minimizes dependence of *R* on *n* -- makes projection to 2 dimensions less conservative

CDMS Likelihood Function

Numbers of events — **Energies of events**

$$\mathcal{L} = g_{\rm s}(N_{\rm s}|n,w)\,g_{\rm m}(N_{\rm m}|n)\,g_{\rm Si}(N_{\rm Si}|n,w)\prod_{i,j,k} f_{\rm s}(E_{{\rm s},i}|n,w,M)\,f_{\rm m}(E_{{\rm m},j})\,f_{\rm Si}(E_{{\rm Si},k}|n,w,M).$$

13 4 4

Drops out of ratio

Ignore --weak dependence

Poisson probabilities given expected values

expected singles fraction β = 0.91

expected ratio n's in Si to Ge γ = 0.21

expected ratio w's in Si to Ge α < 0.02

$$\begin{aligned}\langle N_{\rm s}\rangle &= n\beta + w,\\ \langle N_{\rm m}\rangle &= n(1-\beta),\\ \langle N_{\rm Si}\rangle &= n\gamma + w\alpha + b_{\rm Si},\end{aligned}$$

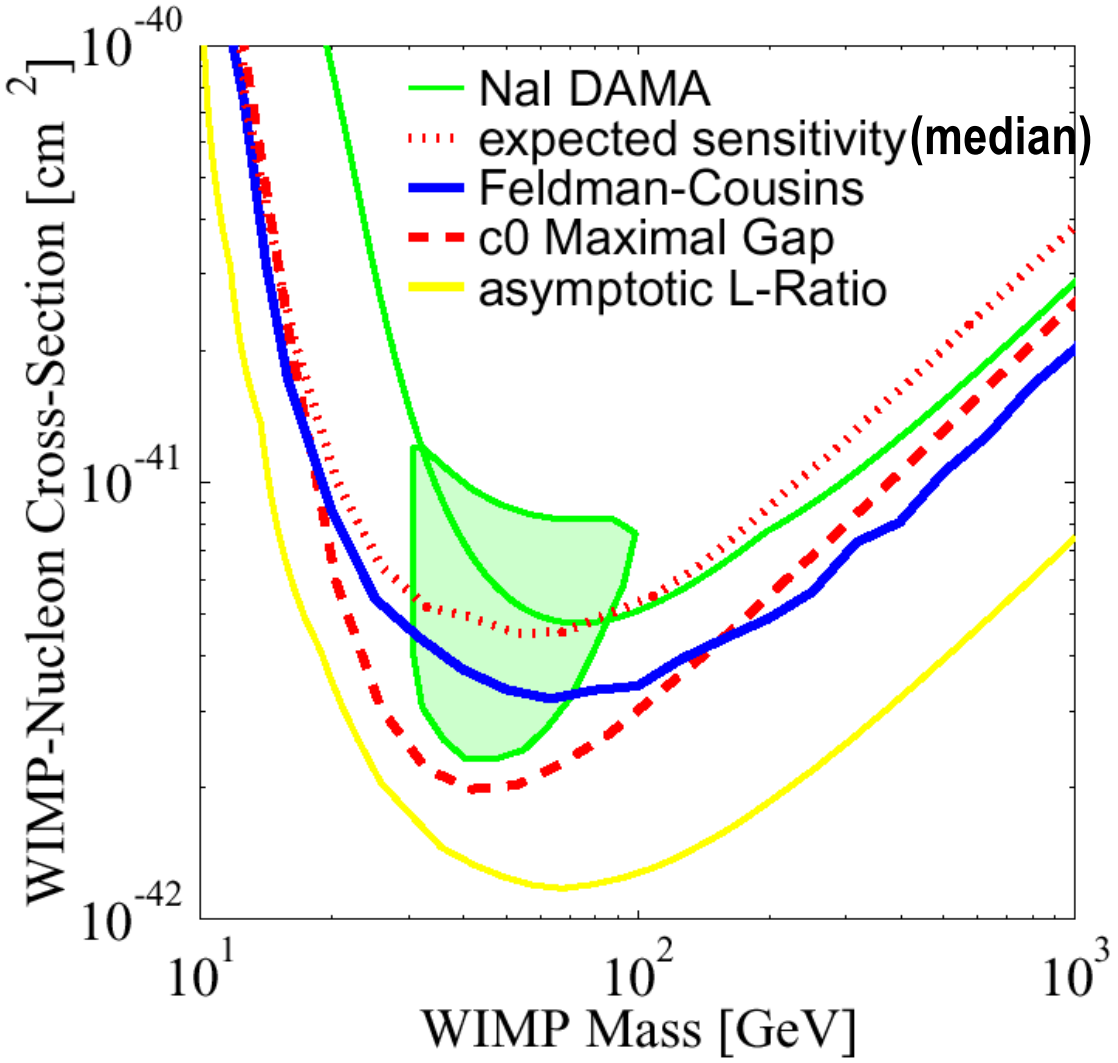
0.76 (conservative)

$$f_{{\rm s},i} = \eta n_{{\rm s},i}\epsilon(E_i) + (1-\eta)w_{{\rm s},i}\epsilon(E_i),$$

neutron spectrum, sum of 2 exponentials

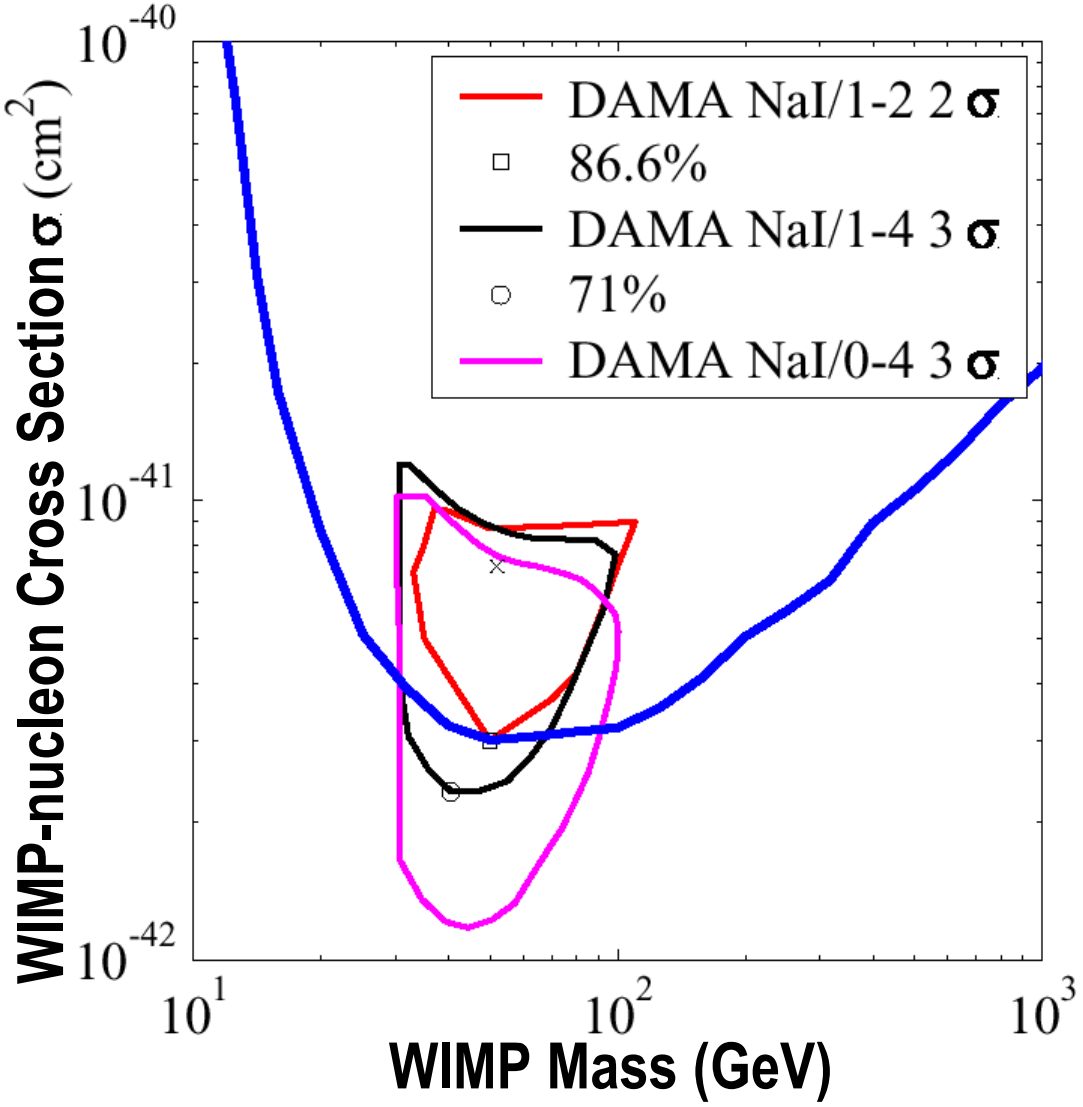
WIMP spectrum ~exponential, f(M)

CDMS Limits



- Because we see more multiple-scatter events than expected, limits are 50% better than expected sensitivity
- So far Bayesian method done only without energy info; results are similar to F-C.
- See http://dmtools.berkeley.edu/limitplots/ for interactive dark matter limit plotting

Compatibility with DAMA Regions



- Bottom of DAMA NaI/1-2 2σ (~87%) region excluded at 86.6% CL
- Bottom of DAMA NaI/1-4 3σ (~99%) region excluded at 71% CL
- It does not make sense to compare to DAMA NaI/0-4 region

Likelihood Ratio Test to Determine Compatibility

- **Likelihood ratio test**

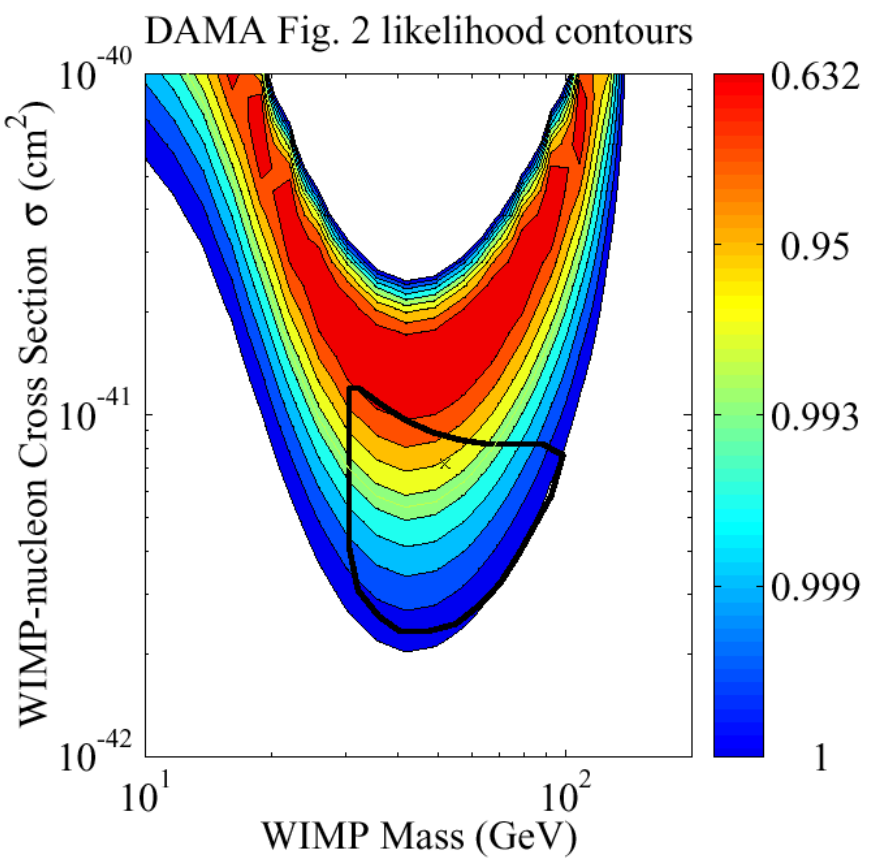
Assume compatibility for single (M,σ)

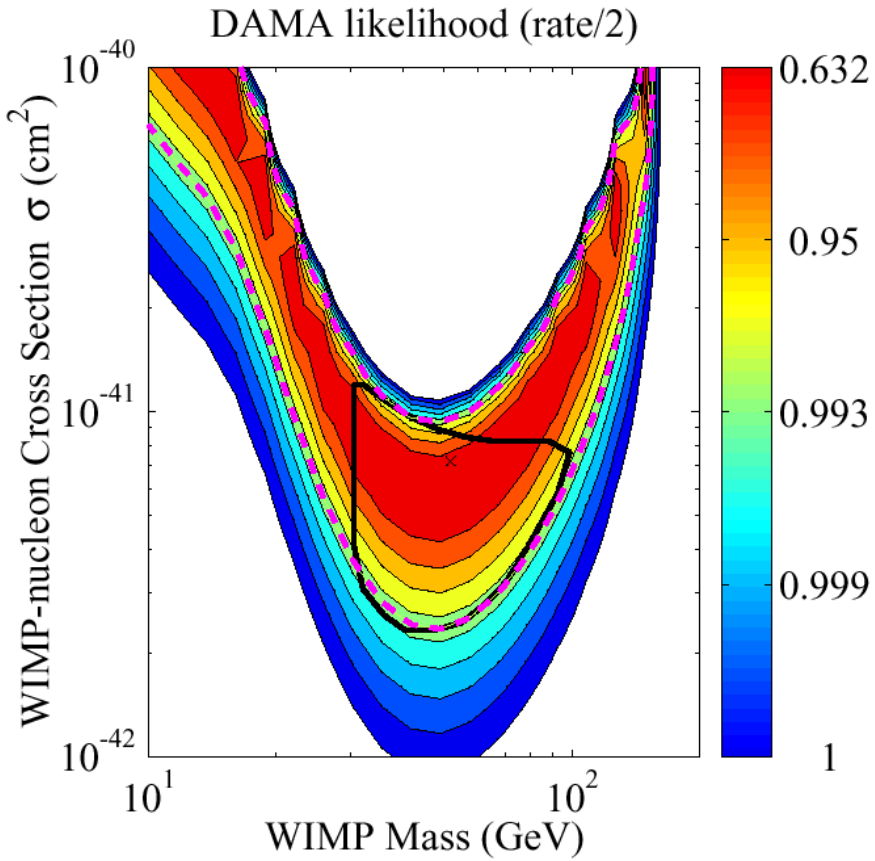
$$R = \frac{L(X \mid \hat{M},\hat{\sigma})}{L(X \mid \hat{M}_c\hat{\sigma}_c\hat{M}_d\hat{\sigma}_d)} = \frac{L(X_c \mid \hat{M},\hat{\sigma})L(X_d \mid \hat{M},\hat{\sigma})}{L(X_c \mid \hat{M}_c\hat{\sigma}_c)L(X_d \mid \hat{M}_d\hat{\sigma}_d)}$$

Allow separate $(M_c,\sigma_c,M_d,\sigma_d)$

  - where ***X*** are the observations of both experiments, $(\hat{M},\hat{\sigma})$ are the values of WIMP mass and cross-section that maximize the likelihood of the two experiments together, and $(M_c,\hat{\sigma}_c)$ and $(M_d,\hat{\sigma}_d)$ are the values that maximize the likelihoods for CDMS and DAMA separately.
  - Ideally, would like to determine significance of test from Monte Carlo
  - Asymptotically (and far from the physical boundaries), -2*log* R behaves as a χ^2 with *2* degrees of freedom(due to 2 constraints in null hypothesis that $M_c = M_d$ and $\sigma_c = \sigma_d$).
  - Requires correct likelihood contours for DAMA.
  - Accuracy depends on how close we are to the asymptotic limit.
  - Results otherwise easy to interpret; no dependence on true values (M,σ)

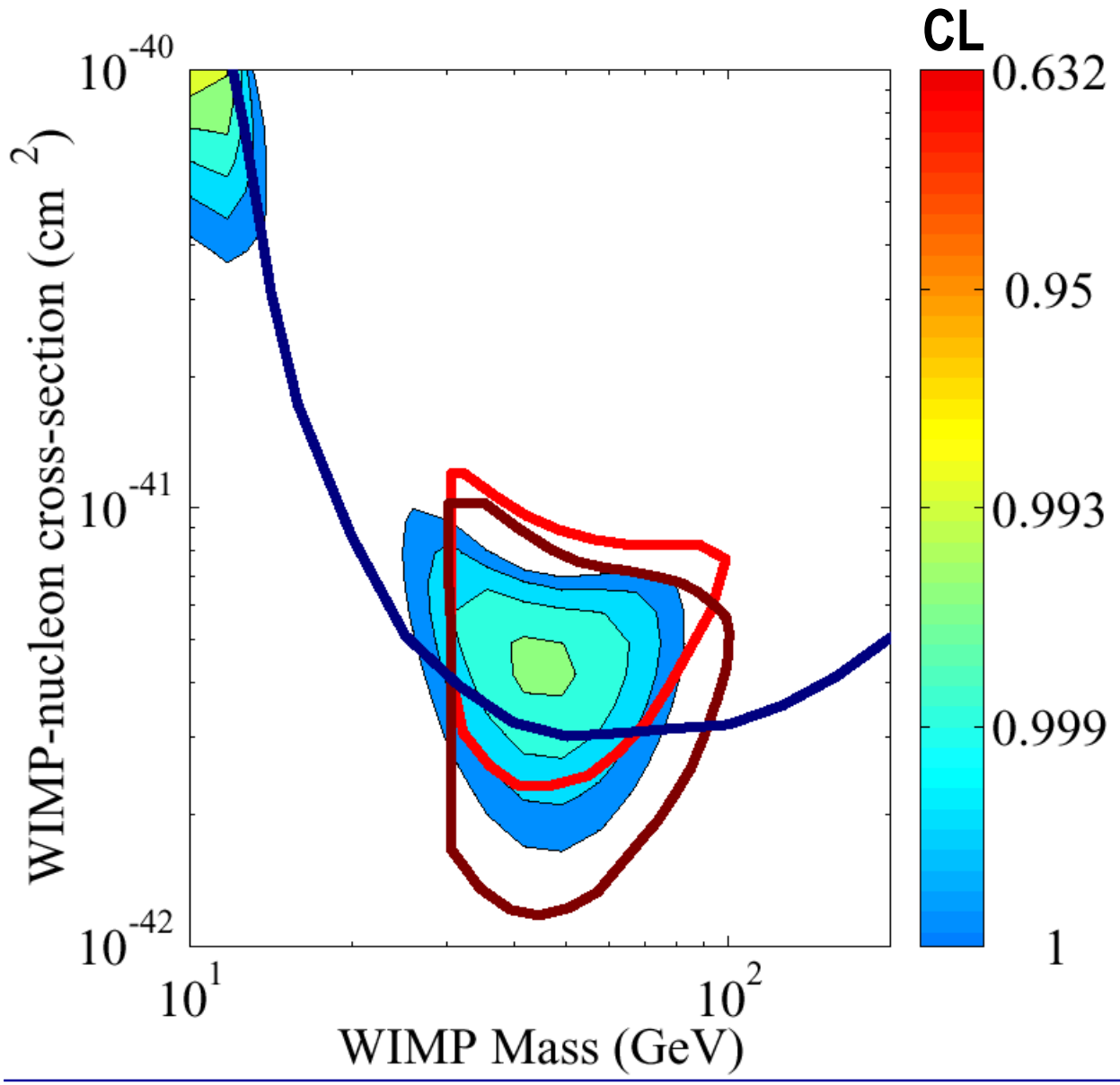
Estimating DAMA's Likelihood Function





- **Need unpublished data for accurate estimate**
  - Contours based on their Fig 2 are too high in cross sections
- **Fake it with published uncertainties, rate/2**
  - 3σ contour (maroon dash) matches published (black) ok

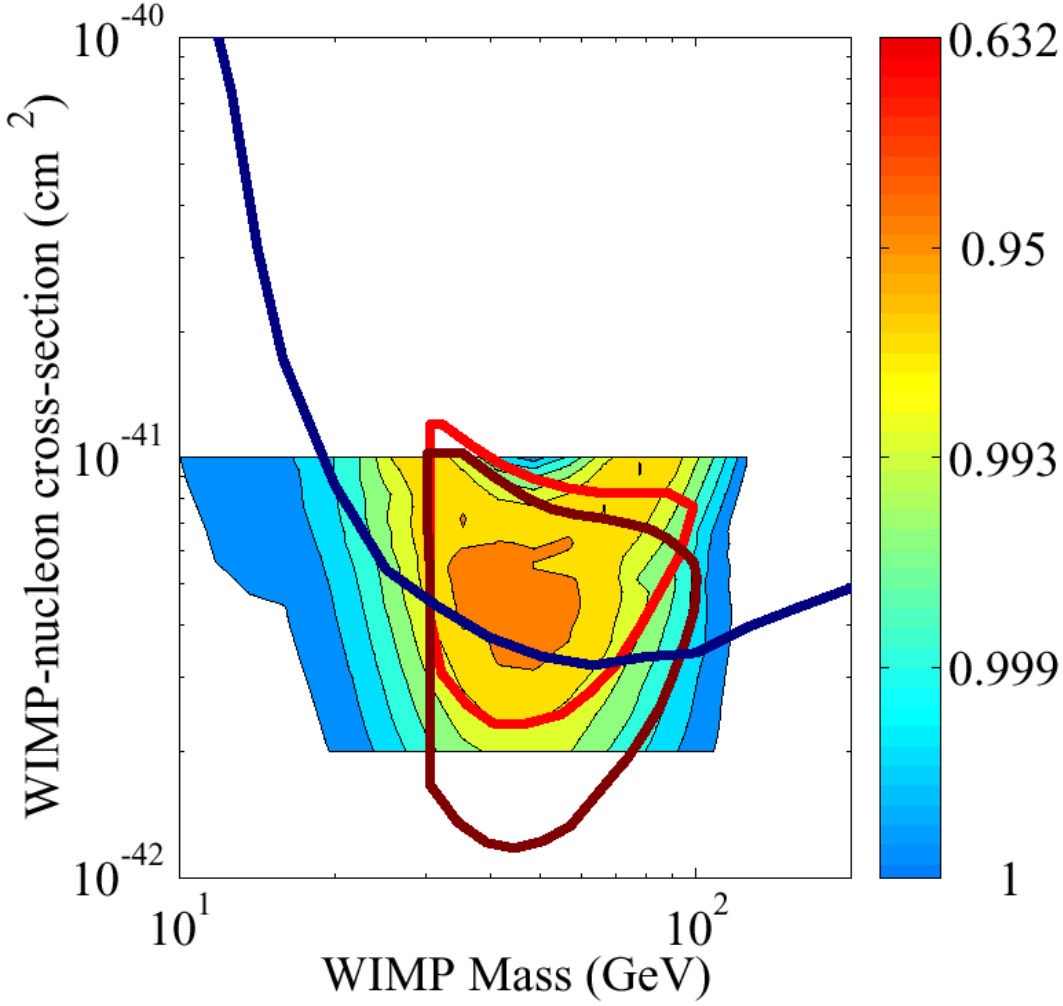
Results of Likelihood Ratio Test



- Two experiments are incompatible at 99.7% CL
- Assumes asymptotic approximations
- Likelihood function for DAMA is estimated (ok match to 3σ contour)

Combining Significance of Both Experiments

- Given significance $\alpha \equiv$ 1 – CL (at a point in parameter space), $\alpha_{BOTH} = \alpha_{CDMS}\alpha_{DAMA}(1 - \log \alpha_{CDMS}\,\alpha_{DAMA})$



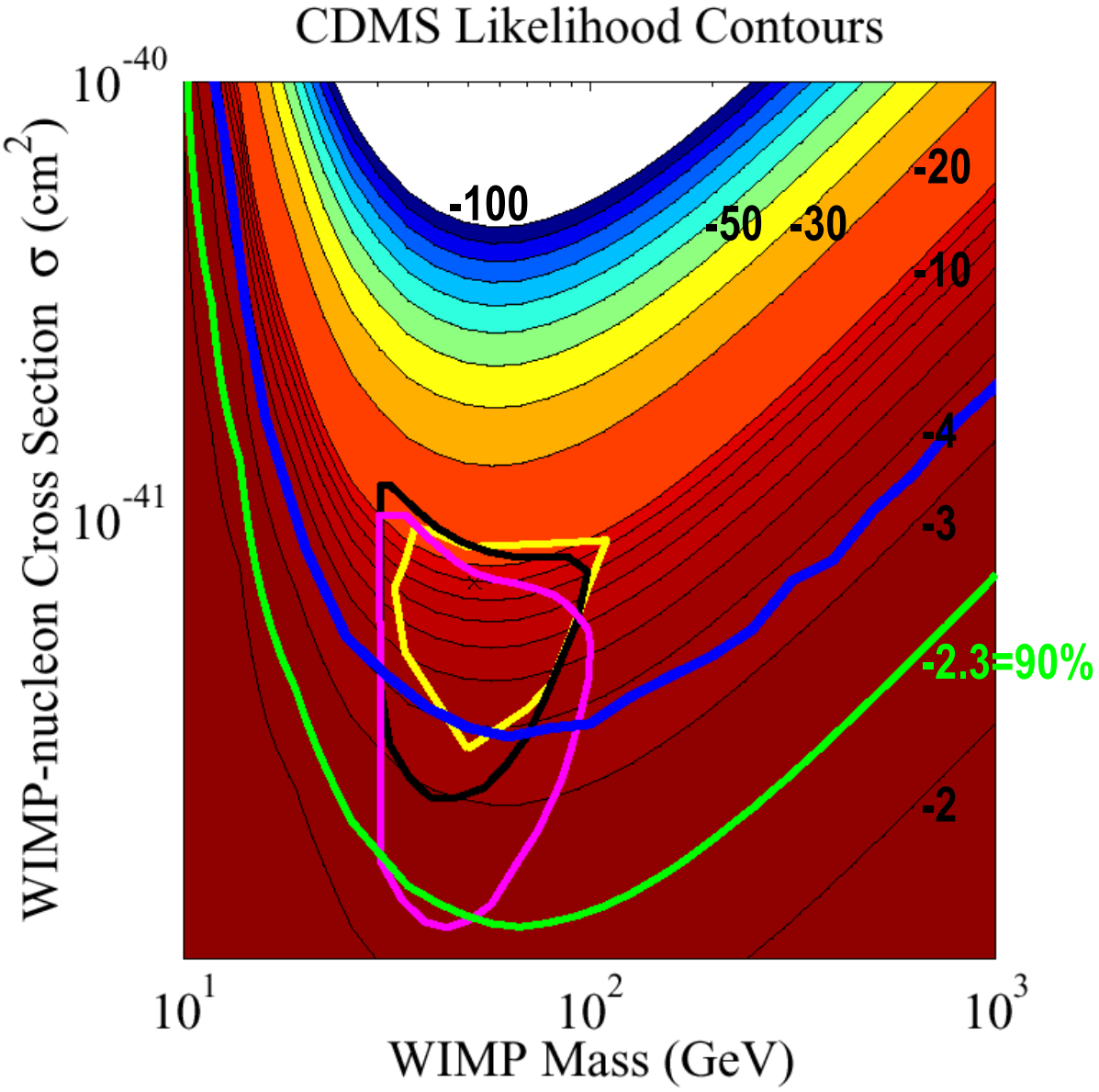
- Estimate DAMA CL from likelihood estimate, assuming asymptotic approximation is ok
- Calculate CDMS CL using Feldman-Cousins Unified Approach (PRELIMINARY; Monte Carlo simulation in progress)
- Two experiments are incompatible at ~91% CL for most likely joint parameters (other parameters even less likely to give results of both experiments)

Conclusions

- Interesting new test case for different methods for calculating limits (and compatibility of experiments)
  - Background neutron rate *n* is nuisance parameter
    - Substituting most likely value of *n* into likelihood ratio works well
  - Neutron rate estimated by multiples & Silicon data is larger than total rate observed (limit beats expected sensitivity)
  - Statistical uncertainty on rate estimated by multiples and Silicon data is large
- Estimated compatibility with incomplete information
  - Bottom of DAMA 3σ region excluded at 71% CL
  - Estimated DAMA likelihood function, confidence contours
  - Two experiments incompatible at >~91% CL (PRELIMINARY)

CDMS Likelihood Contours

- Contours of Δlog L = -1,-2, …,-10,-20,…,-100
- Equal to χ^2=2,4,…,20,
- Plot DAMA NaI/1-2 2σ region (yellow), DAMA NaI/1-4 (black) and NaI/0-4 (pink) 3σ regions
- Δlog R = -2.3 (χ^2=4.6) curve well below Feldman-Cousins MC 90% CL (so we are far from asymptotic limit)



Test of Compatibility with DAMA

- Compare to region allowed by DAMA signal without including constraint from DAMA's 1996 upper limit
  - Region including this constraint is made under assumption that DAMA's signal and upper limit are both correct -- but this may not be the case. If CDMS is incompatible with DAMA's signal, either DAMA's signal is wrong or CDMS's limit is wrong.
  - The fact that DAMA has data producing an upper limit should not make their signal appear to be more compatible with other upper limits.
  - The large difference between DAMA's two regions is due to fact that their upper limit is already somewhat incompatible with their signal (although not too significantly); the most likely (M,σ) point for their signal is ruled out by their 90% CL upper limit.