Search for Inelastic Dark Matter with the CDMS experiment

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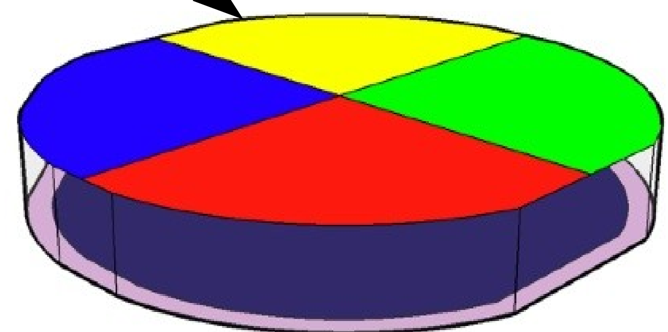
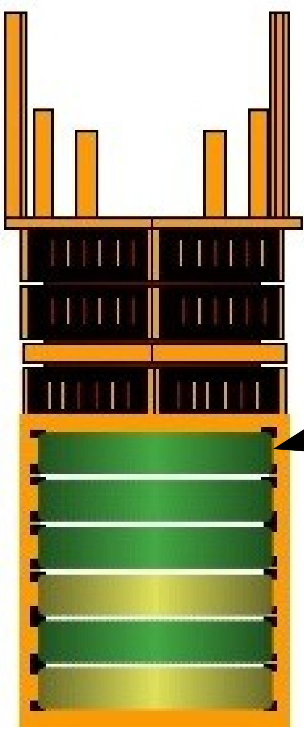
The CDMS experiment

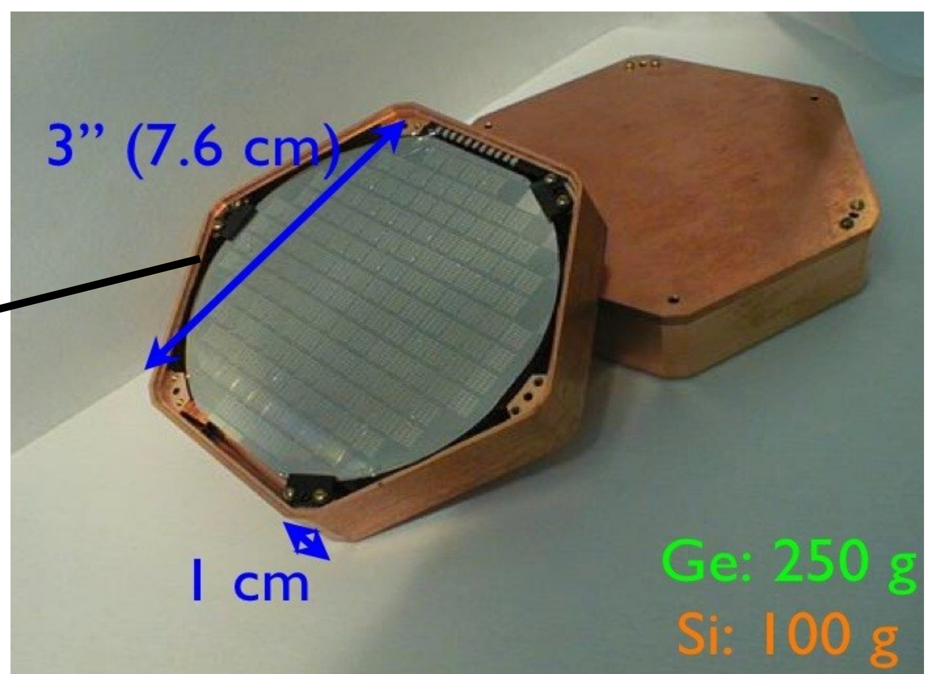
- 19 Ge and 11 Si semiconductor detectors
- 5 towers with 6 detectors each
- operated at cryogenic temperatures (~40 mK)
- 2 signals from interaction (ionization and phonon) → event by event discrimination between electron recoils and nuclear recoils

Phonon readout:
4 quadrants of
phonon sensors



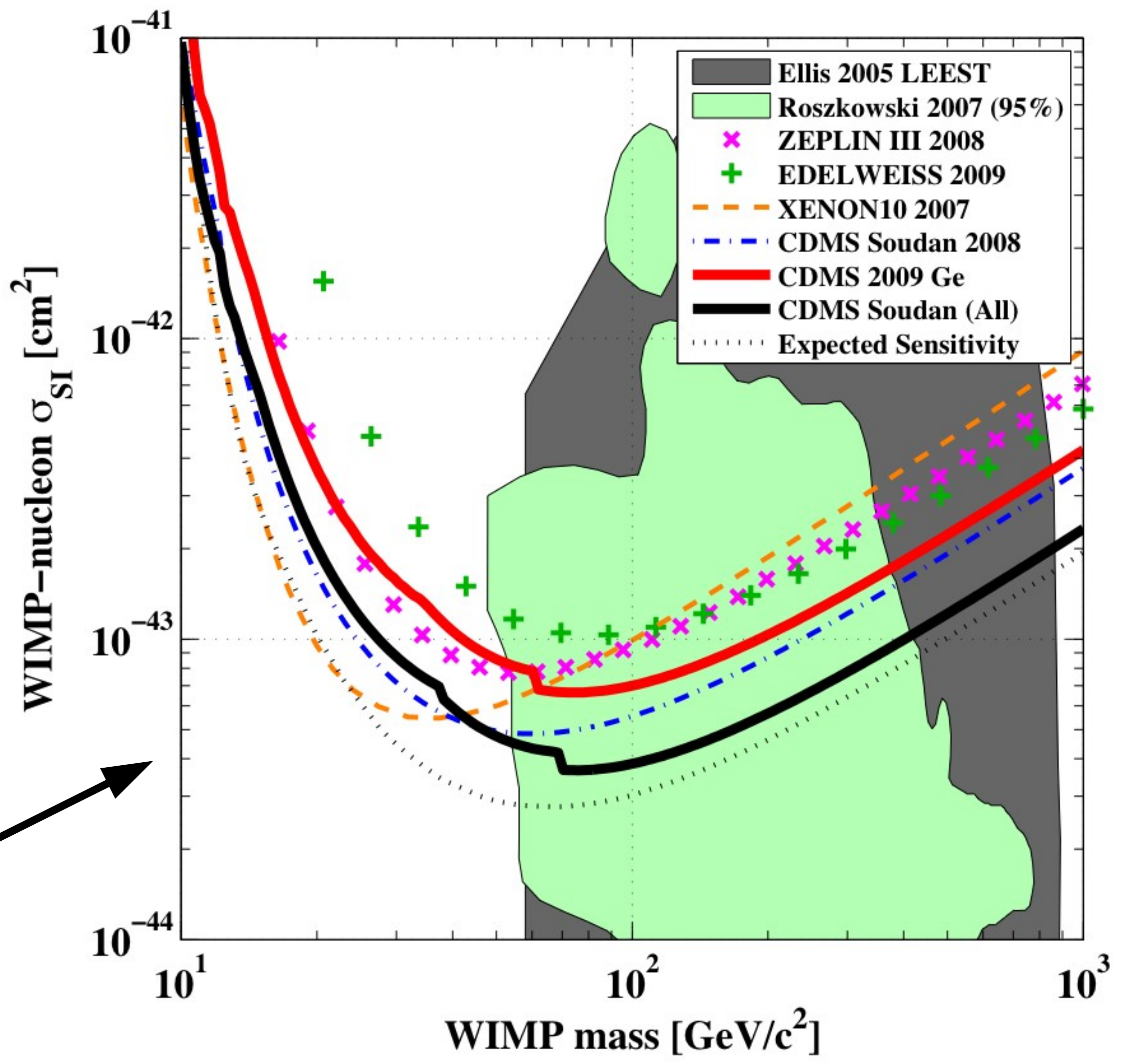
Charge readout:
2 concentric
electrodes





The CDMS results

- important facts about the “standard“ analysis:
    - 2 events observed at 12.3 keV and 15.5 keV
    - background of 0.9±0.2 events predominantly surface events
    - probability for two or more background events is 23%
- use this result to constrain the Standard WIMP model (elastic spin-independent scattering, iso-thermal halo described by Maxwellian velocity distribution)



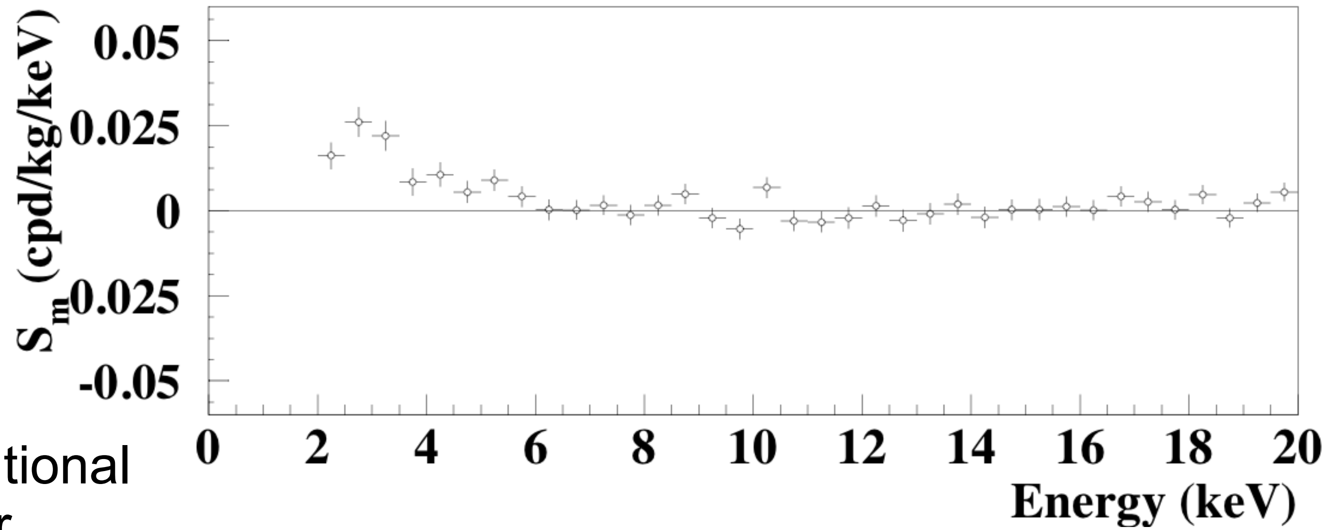
What else can we do with the data? → Test inelastic dark matter model!

The DAMA/LIBRA results

- observation of annual modulation at low recoil energies (2-4 keV)

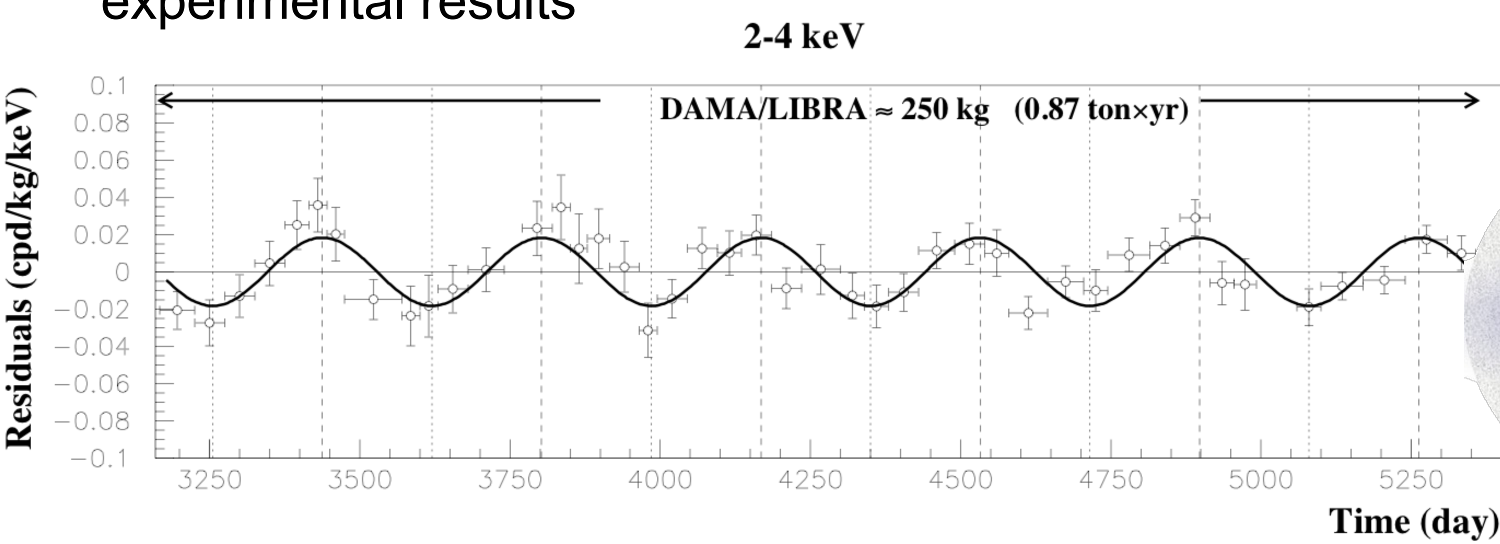
$$\frac{dR}{dE}(E,t) = S_0(E) + S_m(E)\cdot\cos\left(\omega(t-t_0)\right)$$

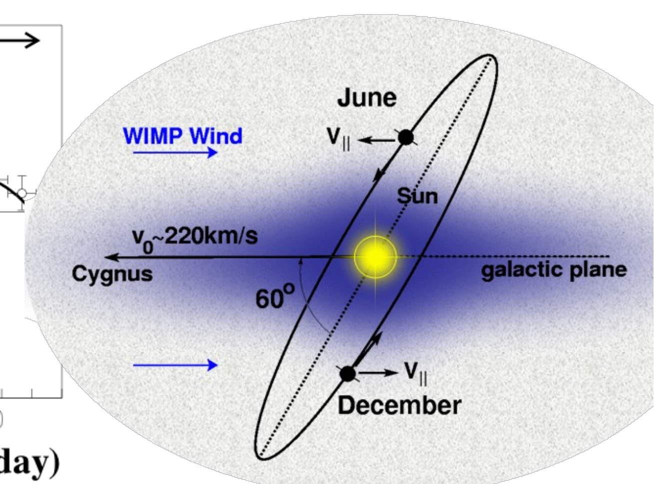
- evidence @ 8.9σ C.L.



- measured over 13 annual cycles with exposure of 1.17 ton-years

- difficulties to explain this observation with the conventional WIMP model in light of other experimental results





Inelastic Dark Matter (IDM)

- 2 dark matter states with mass splitting δ ~100 keV

- WIMP-nucleus scattering through transition of WIMP into excited state WIMP*

- elastic scattering forbidden or highly supressed

- minimum velocity is increased

$$v_{\rm min} = \frac{1}{\sqrt{2 m_T E_{\rm rec}}}\left(\frac{m_T E_{\rm rec}}{\mu} + \delta\right)$$

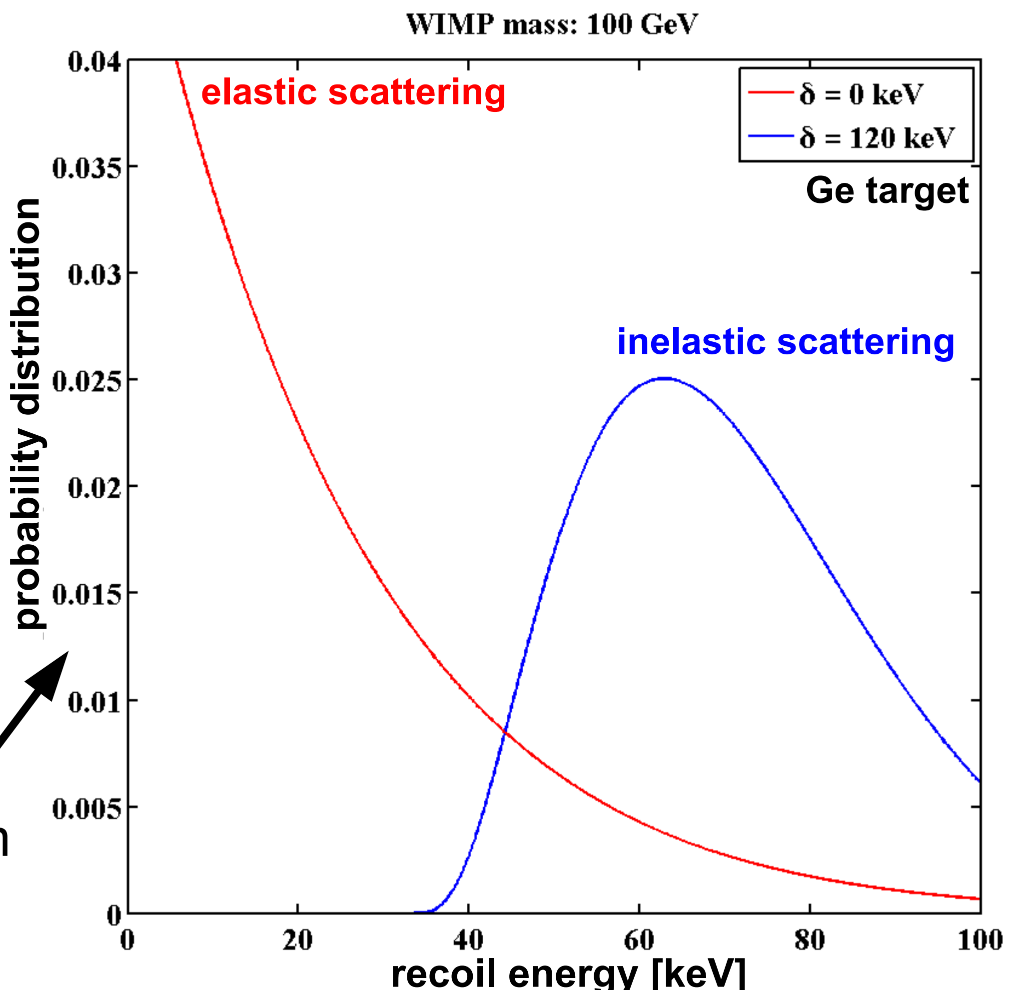
- experiments probe “higher“ part of velocity distribution

- high sensitivity to escape velocity cut-off

- heavy targets are favoured

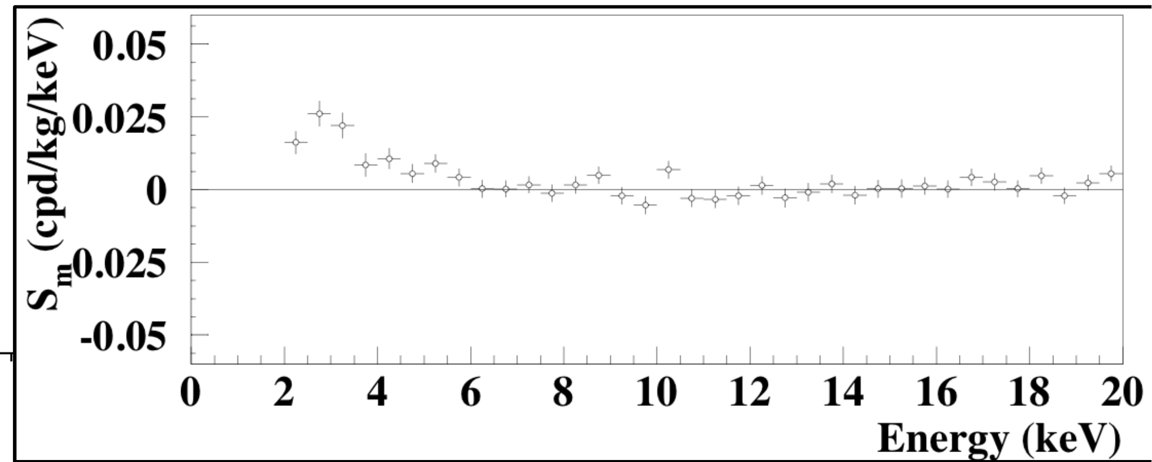
- significant change of the energy spectrum

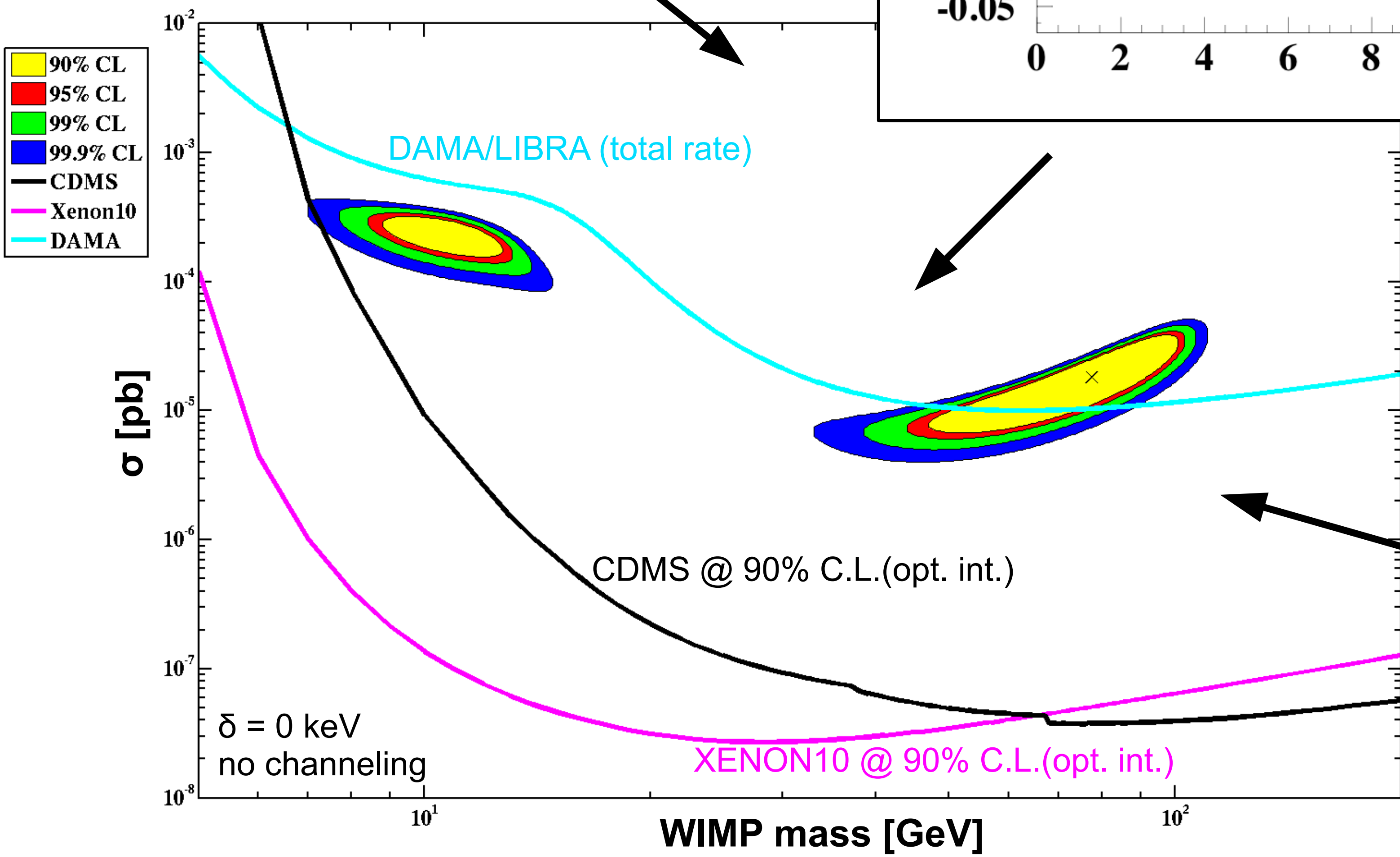
- enhancement of annual modulation



The DAMA/LIBRA allowed region

$$S_m(\mathrm{E}) = \frac{1}{2}\left(\frac{\mathrm{dR}}{\mathrm{dE}}(\mathrm{E}, 2^{\mathrm{nd}}\mathrm{June}) - \frac{\mathrm{dR}}{\mathrm{dE}}(\mathrm{E}, 2^{\mathrm{nd}}\mathrm{Dec})\right)$$





χ^2-goodness-of-fit-test with 17 degrees of freedom (10 – 20 keV combined into one bin)

constrain absolute value of χ^2 **not** $\Delta\chi^2$ with respect to the minimum

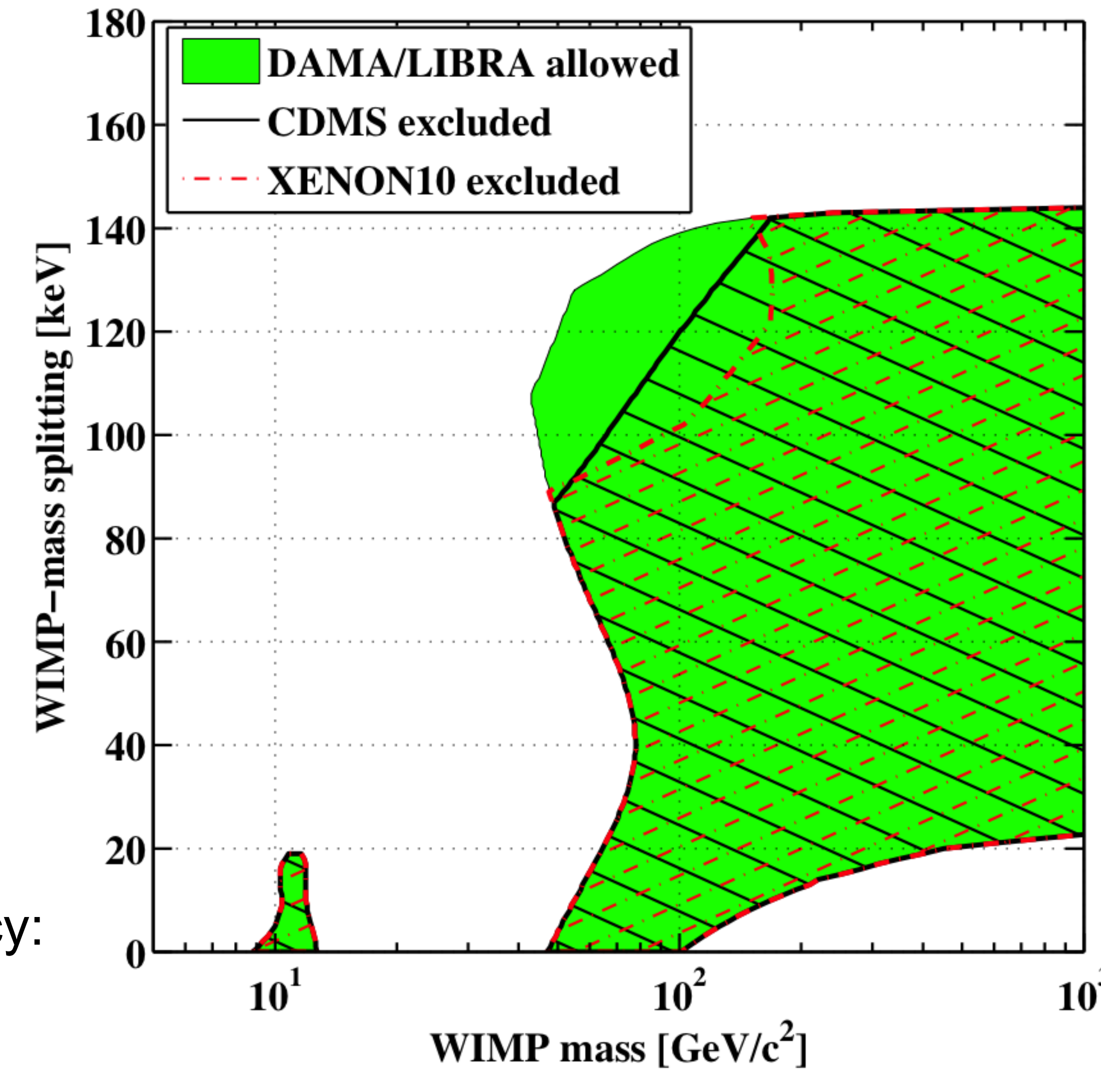
First constraints on IDM from CDMS

- Excluded regions are defined by demanding the upper limit on the cross section to completely rule out the DAMA/LIBRA allowed cross section intervals at a given WIMP mass and mass splitting.

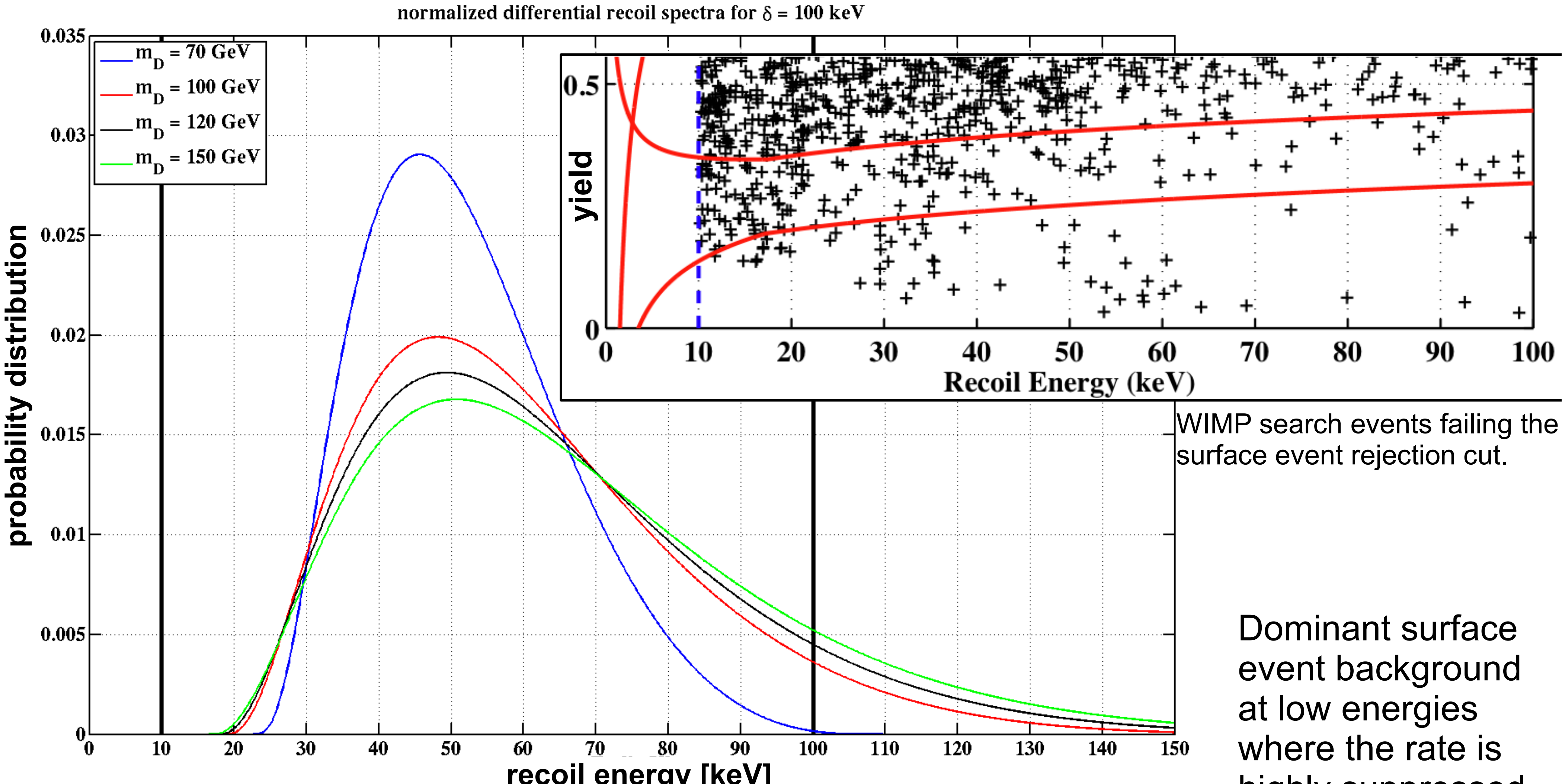
- all limits/allowed regions are @ 90% C.L.

- optimum interval method is used for CDMS and XENON10

- used parameters are important:
  - escape velocity:
    - v_{esc} = 544 km/s
  - DAMA quenching factors:
    - q_I = 0.09
    - q_{Na} = 0.30
  - XENON10 scintillation efficiency:
    - L_{eff} = 0.19



How can we improve the sensitivity?



WIMP search events failing the surface event rejection cut.

Dominant surface event background at low energies where the rate is highly suppressed.

Differential rates in allowed parameter space extend to energies above upper analysis limit (100 keV).

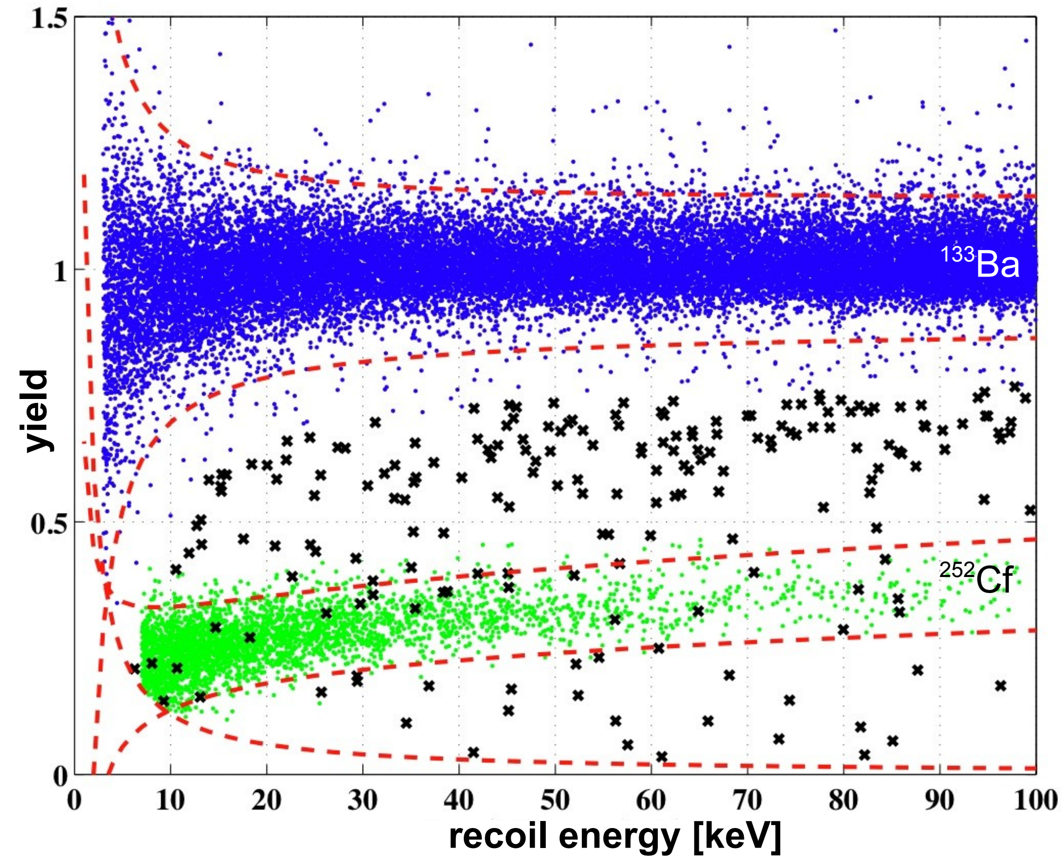
Simply extend analysis range to 150 keV!

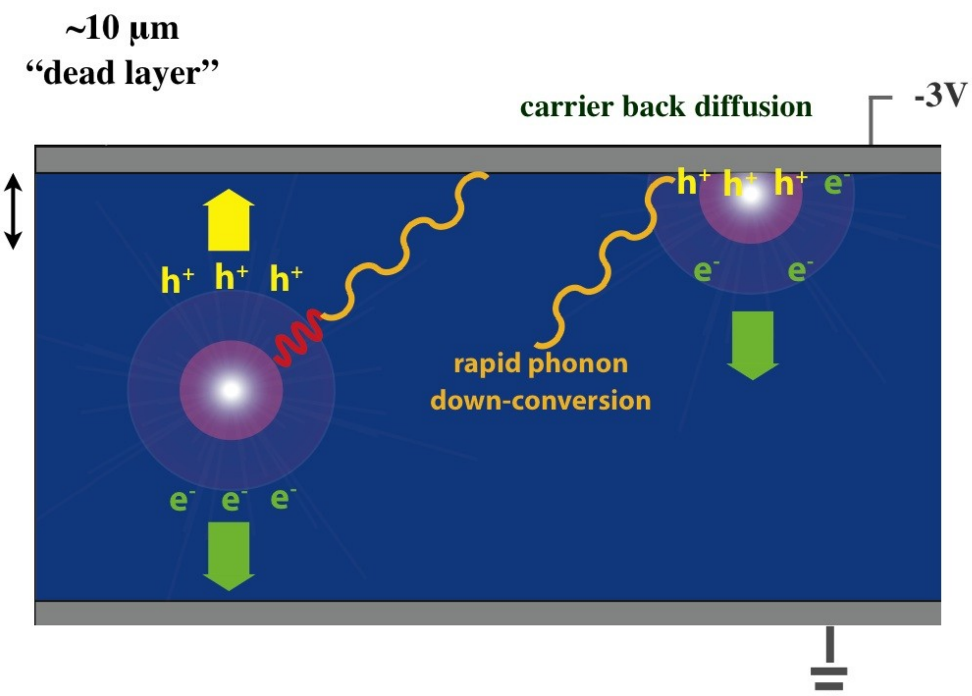
Improve surface event rejection cut!
Use all 6 five tower runs!

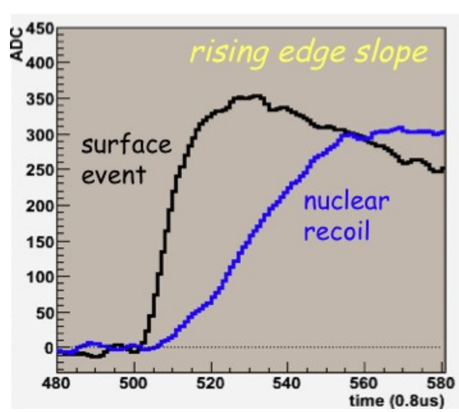
Surface events

- reduced charge collection due to backdiffusion of charge carriers at the detector surface

- sources:
  1. low-energy electrons from the ambient photon-flux from radioactive impurities in the experimental setup
  2. ^{210}Pb contamination of the detector surfaces







Surface events are faster in timing than bulk nuclear recoils.

Use timing as discriminator.

A new surface event rejection cut

need to use combined 5 tower data from all 6 runs (969.4 kg-days, germanium detectors only)

tighter timing cut for given leakage

lower efficiency

set new timing cut in the energy range of 25-150 keV to evade most of the leakage

looser timing cut for given leakage

higher efficiency

Which effect will be stronger?

New Timing Cut

optimize timing cut for WIMP mass of 100 GeV and mass splitting of 120 keV

Analysis is **not** blind! But use only timing information from calibration data for setting the cut, **not** from WIMP search data.

Setting the timing cut

- estimate distribution of californium calibration data in each detector z → nuclear recoil efficiency ϵ

- compute differential rate for WIMP mass of 100 GeV and mass splitting of 120 keV

spectrum averaged exposure $SAE_z(t_z)$

$$SAE = mT \frac{\int dE \frac{dR}{dE} \epsilon(E)}{\int dE \frac{dR}{dE}}$$

- estimate distribution of barium calibration data in each detector z → leakage fraction

- apply correction factors for difference between barium and WIMP search data

- include estimated number of nuclear recoil single scatters

expected leakage $n_z(t_z)$

Minimize $$f(t) = \left(1 - \frac{\sum_z SAE_z(t_z)}{(\sum_z SAE_z)_{max}}\right)^2 + \left(1 - \frac{\sum_z n_z(t_z)}{(\sum_z n_z)_{target}}\right)^2$$

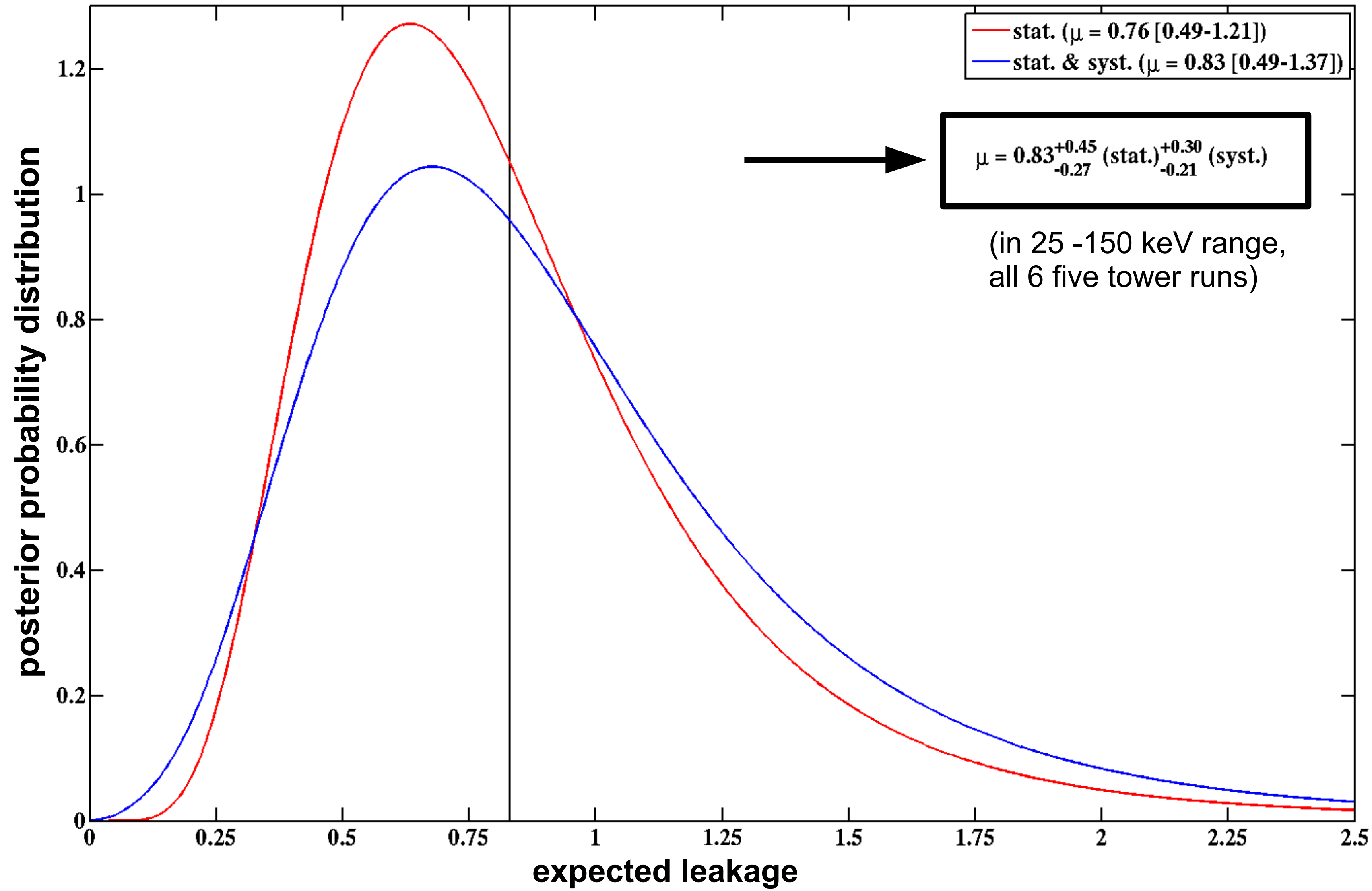
predefined leakage (use 0.6 events)

Surface event leakage estimate

- use WIMP search multiples and singles outside the nuclear recoil band, e.g.

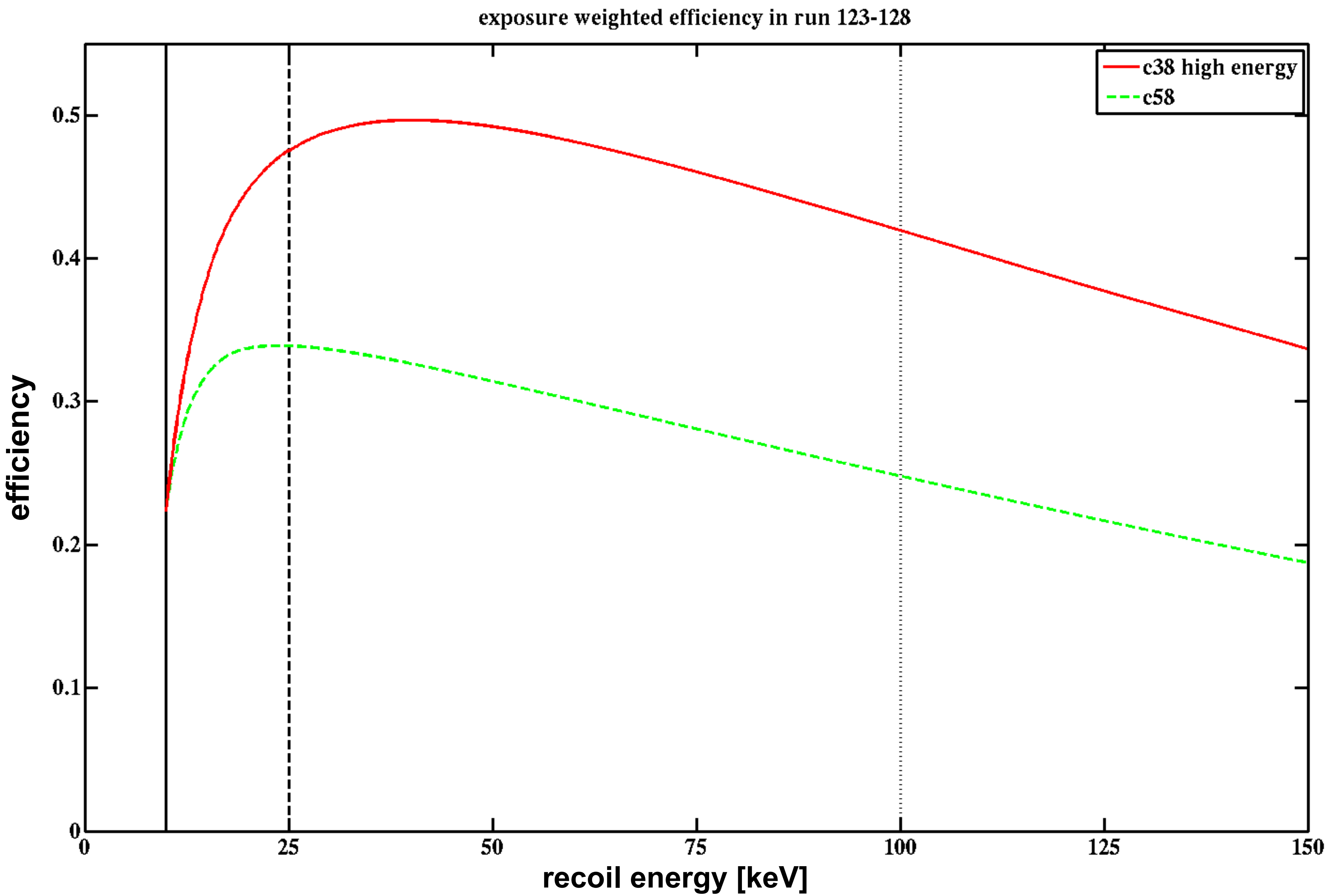
$$\mu = \langle N^{fail}_{sing.} \rangle \cdot \frac{\langle N^{pass}_{mult.} \rangle}{\langle N^{fail}_{mult.} \rangle}$$

- Bayesian approach → treat background as random variable



Efficiency & “Unblinding“

- efficiency increased by a factor ~1.5



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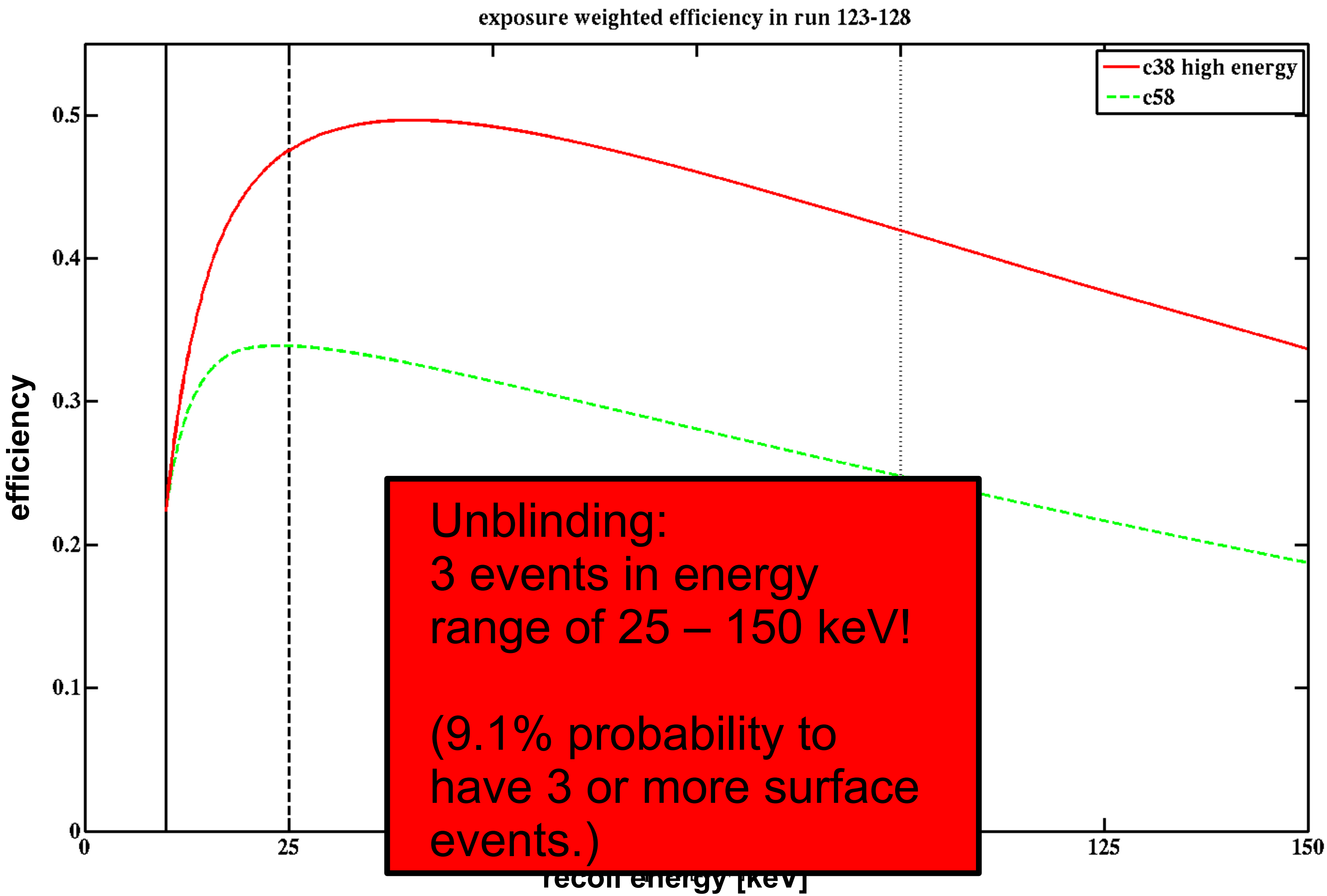


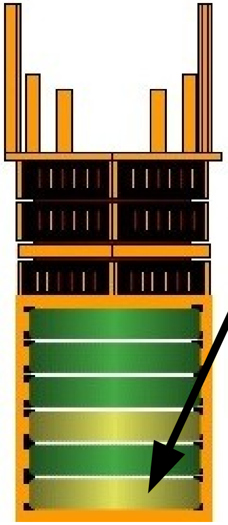
Unblinding:
3 events in energy range of 25 – 150 keV!

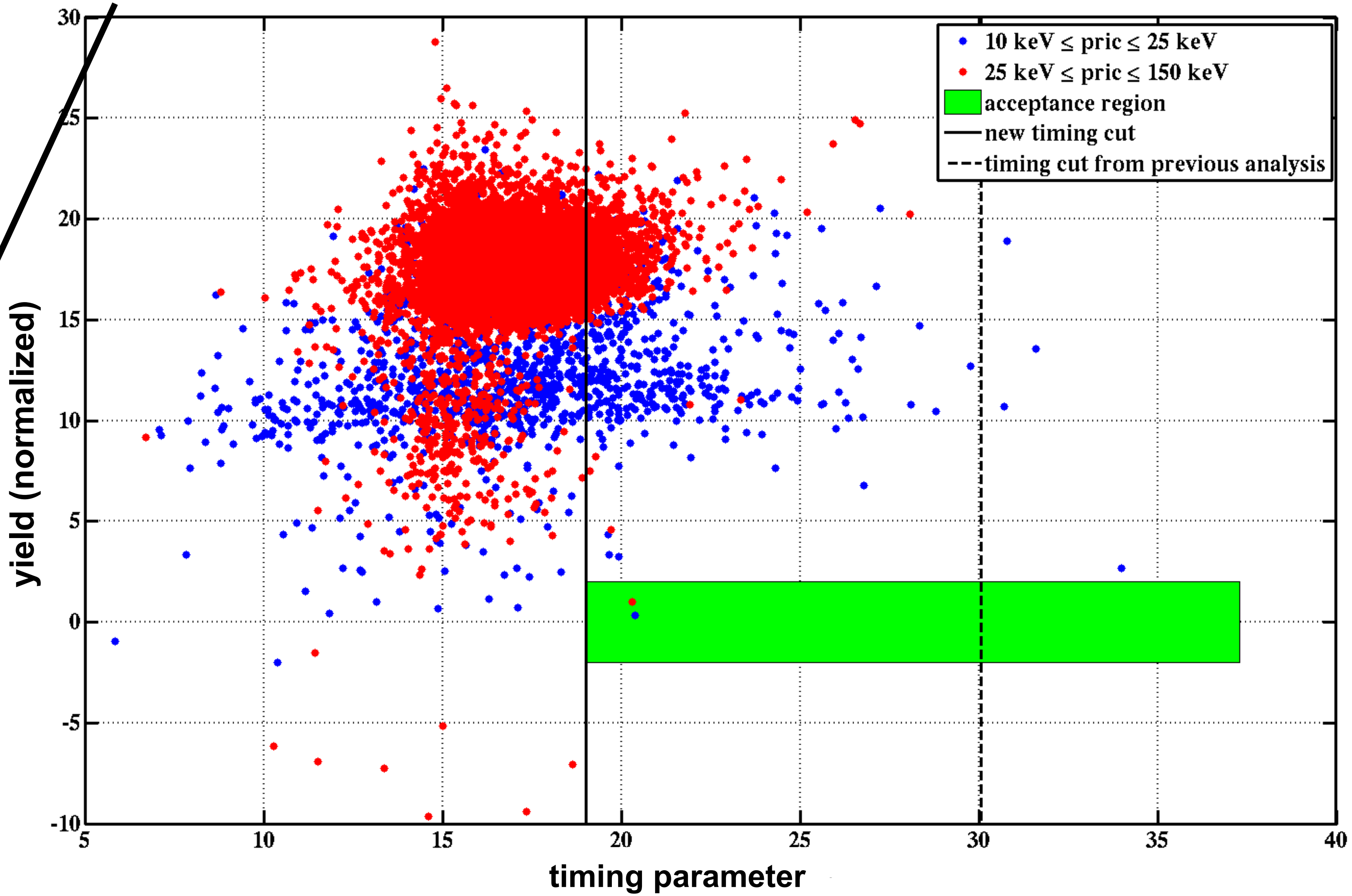
(9.1% probability to have 3 or more surface events.)

Event 1

T4Z6 @ 37.3 keV Feb. 2, 2008

Endcap detector!

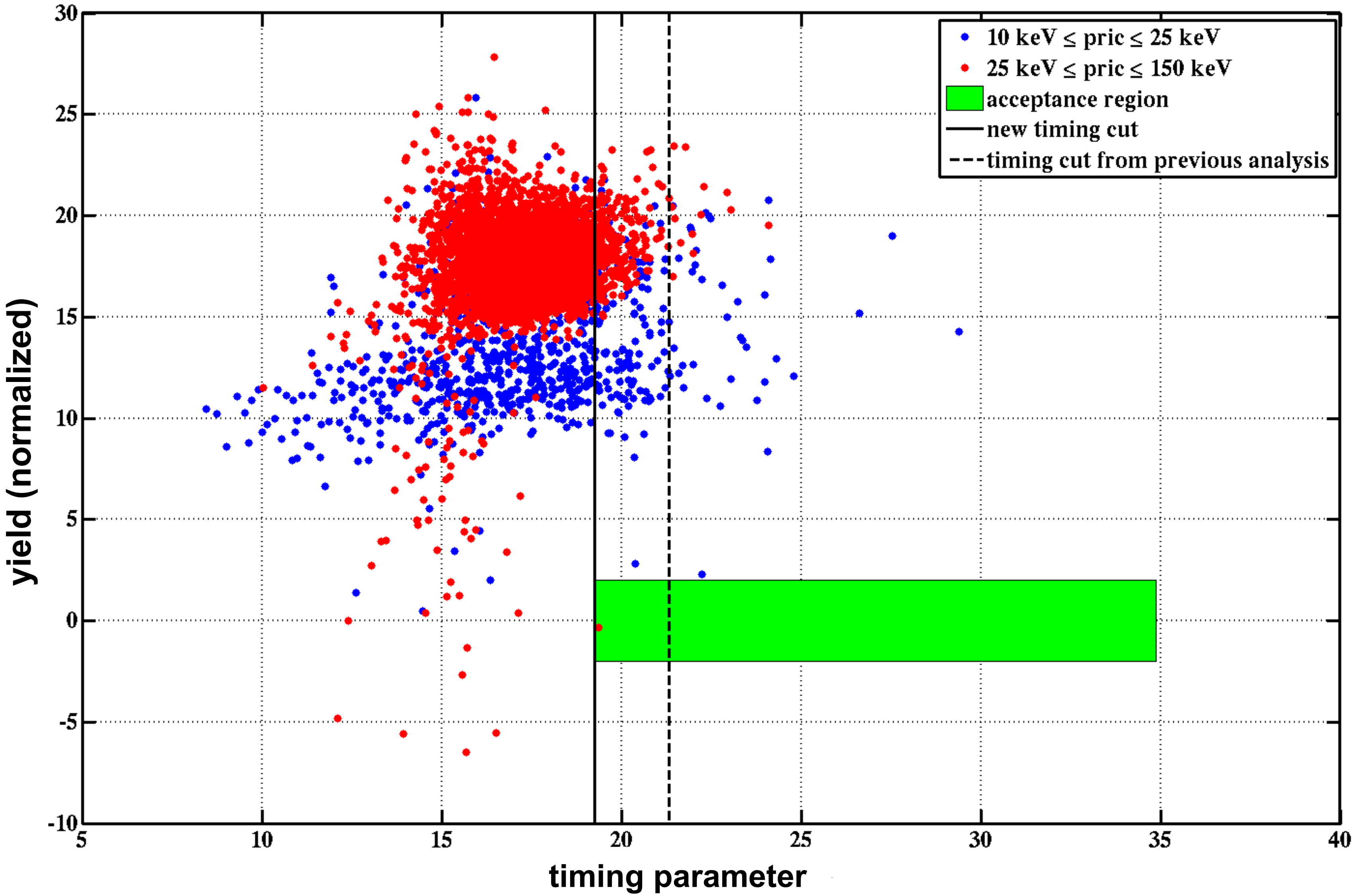




Event 2

T4Z2 @ 73.3 keV Feb. 4, 2008

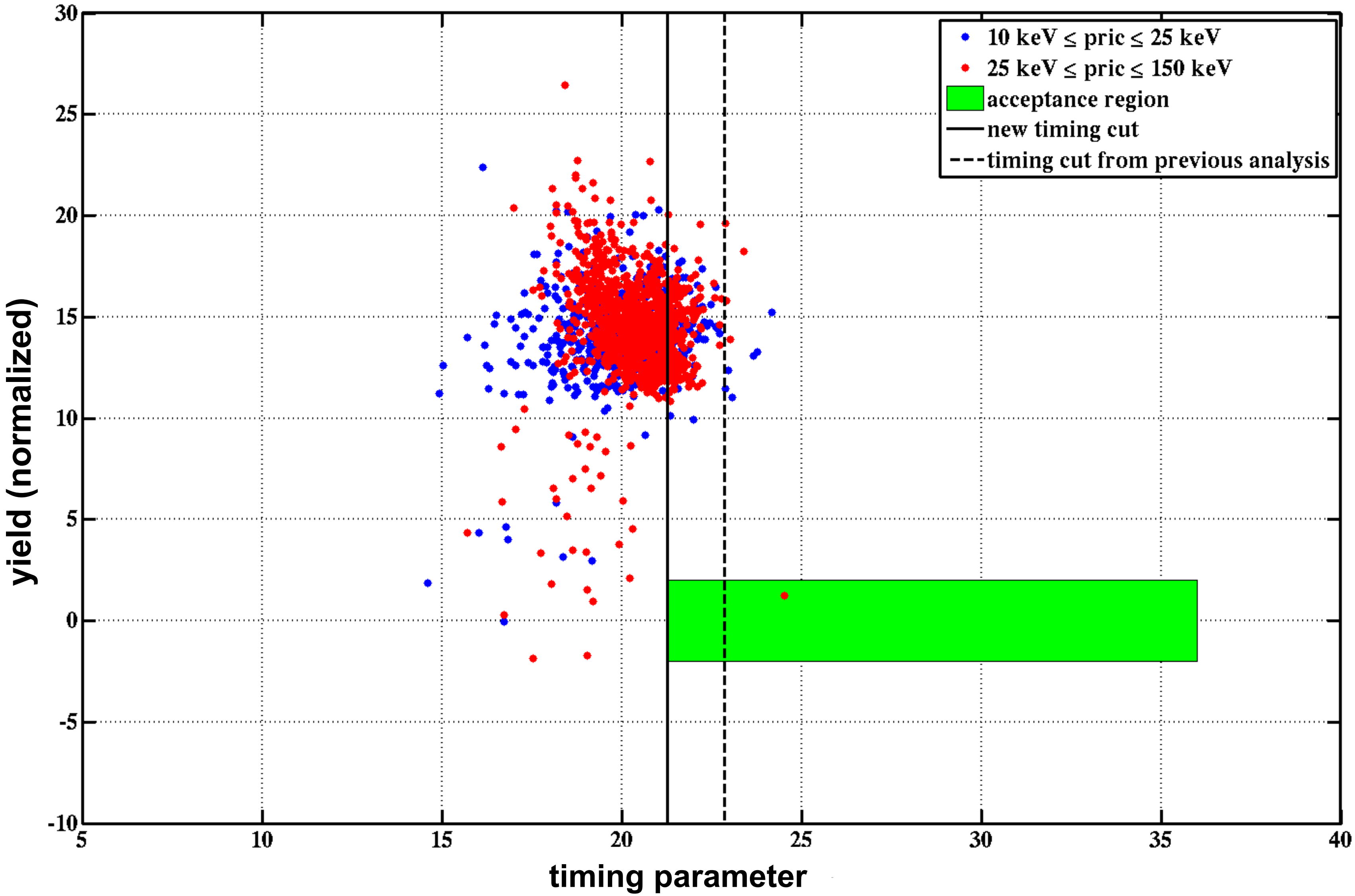
Extremely close to timing cut boundary!



Event 3

T1Z2 @ 129.5 keV Christmas Eve, 2006

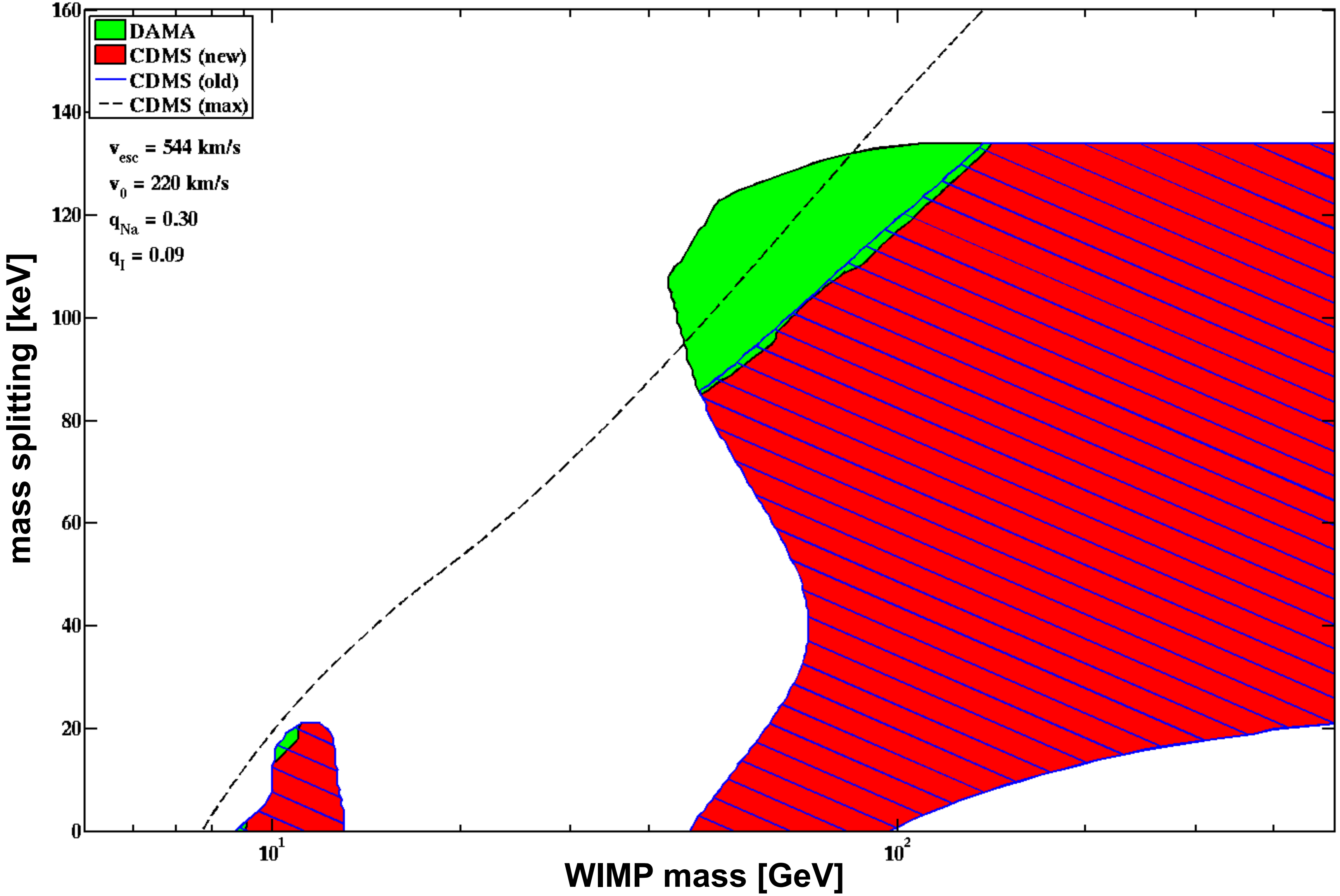
Not even cut by timing cut set to 0.1 leakage events / cut from previous analysis!



Constraining the IDM model

- due to the occurance of 3 events at „high“ energies the limit is weaker

- events between 10 and 25 keV are included for the limit



Summary

- inelastic dark matter analysis including energies up to 150 keV

- improved surface event rejection cut

- expected surface event background in 25 - 150 keV range:

$$\mu = 0.83^{+0.45}_{-0.27}\,(\mathrm{stat.})^{+0.30}_{-0.21}\,(\mathrm{syst.})$$

- efficiency increased by ~1.5 compared to standard analysis

- 3 events observed in 25 - 150 keV energy range:
    - one event very close to the timing cut boundary
    - one event far above the timing cut boundary

- 9.1% probability to observe 3 or more surface events (neutron background currently not included!)

- weaker constraints on IDM parameter space due to occurance of 3 events

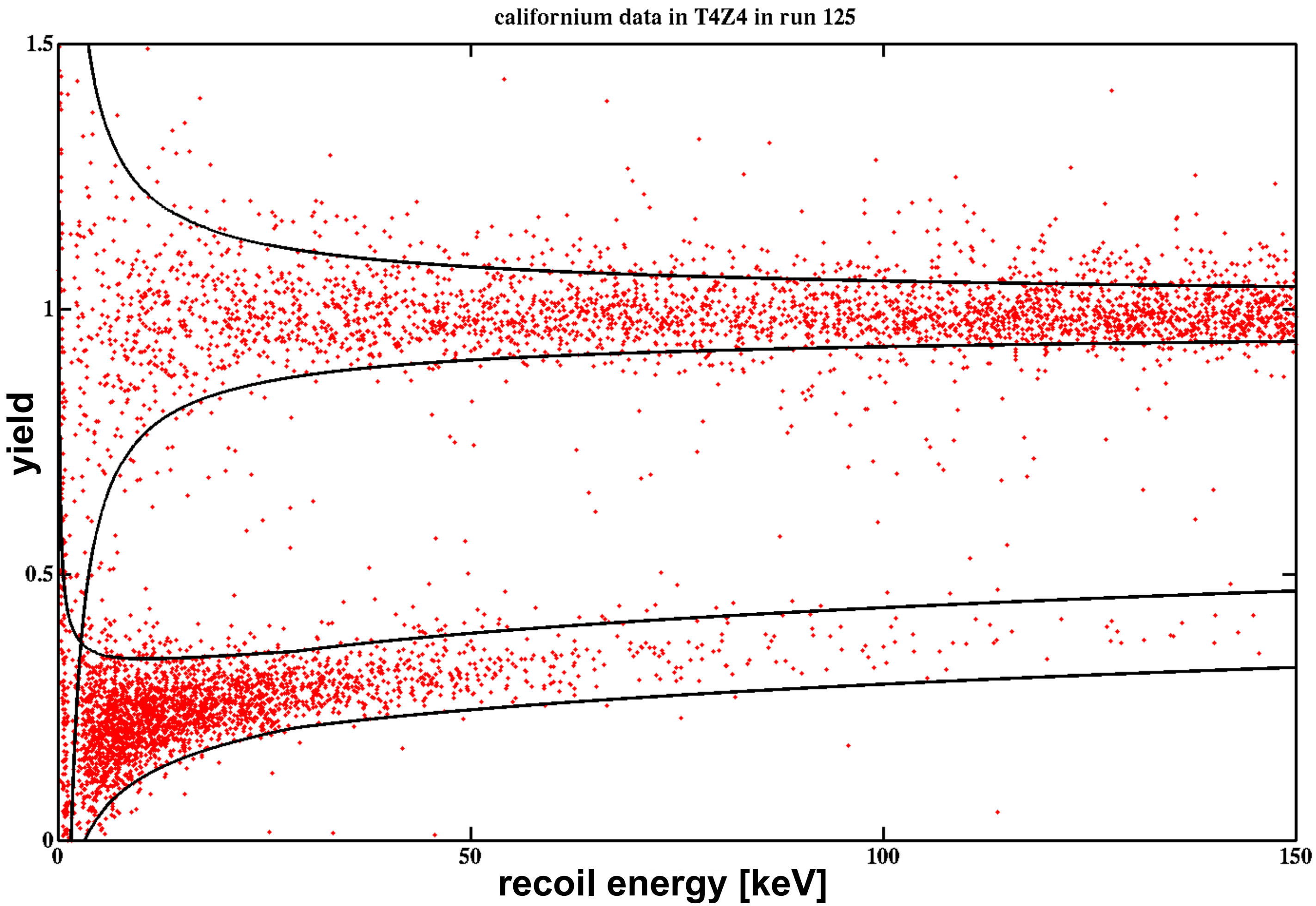
- publication in progress

Backup Slides

Extending the analysis range

- in principle very simple task
- main problem is low statistics in the californium calibration data at energies above ~100 keV
- always check results (cuts/efficiencies) at high energies combining all 6 runs
- compare results from combined data sets with extrapolations from low energies
- be conservative

- No cuts (except surface event rejection) have to be changed.
- Possible WIMP candidates above ~100 keV have to be checked with special care!



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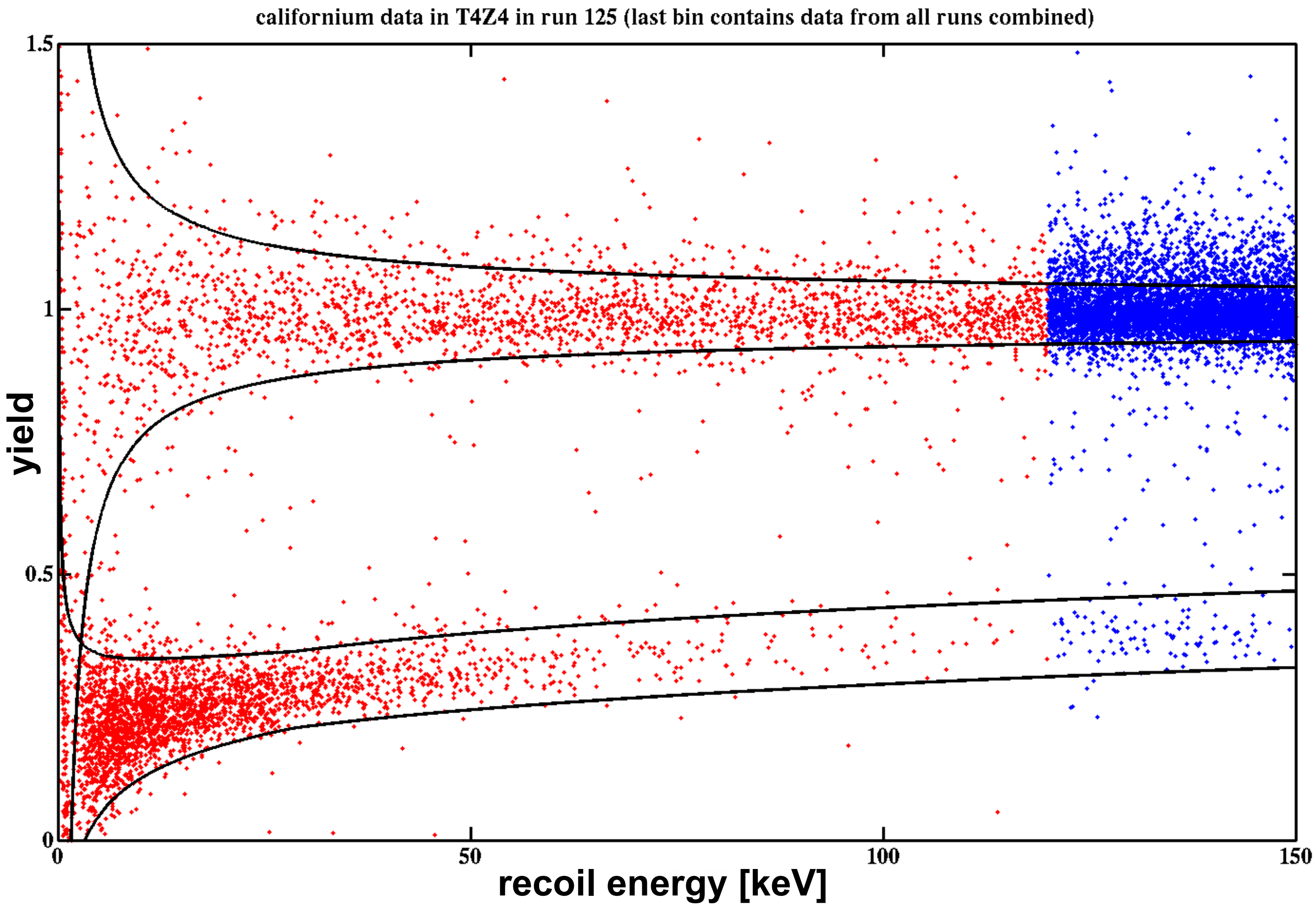
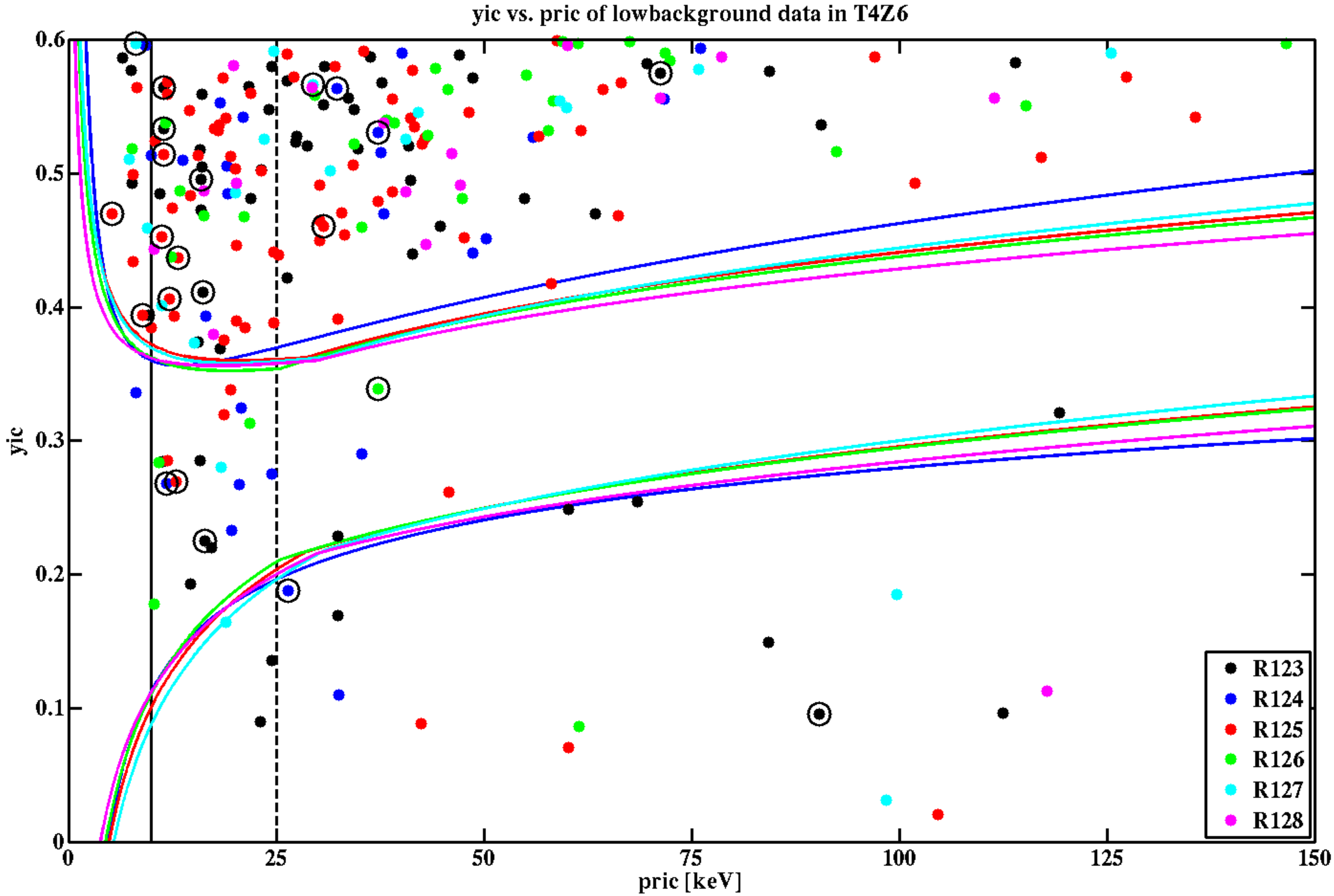
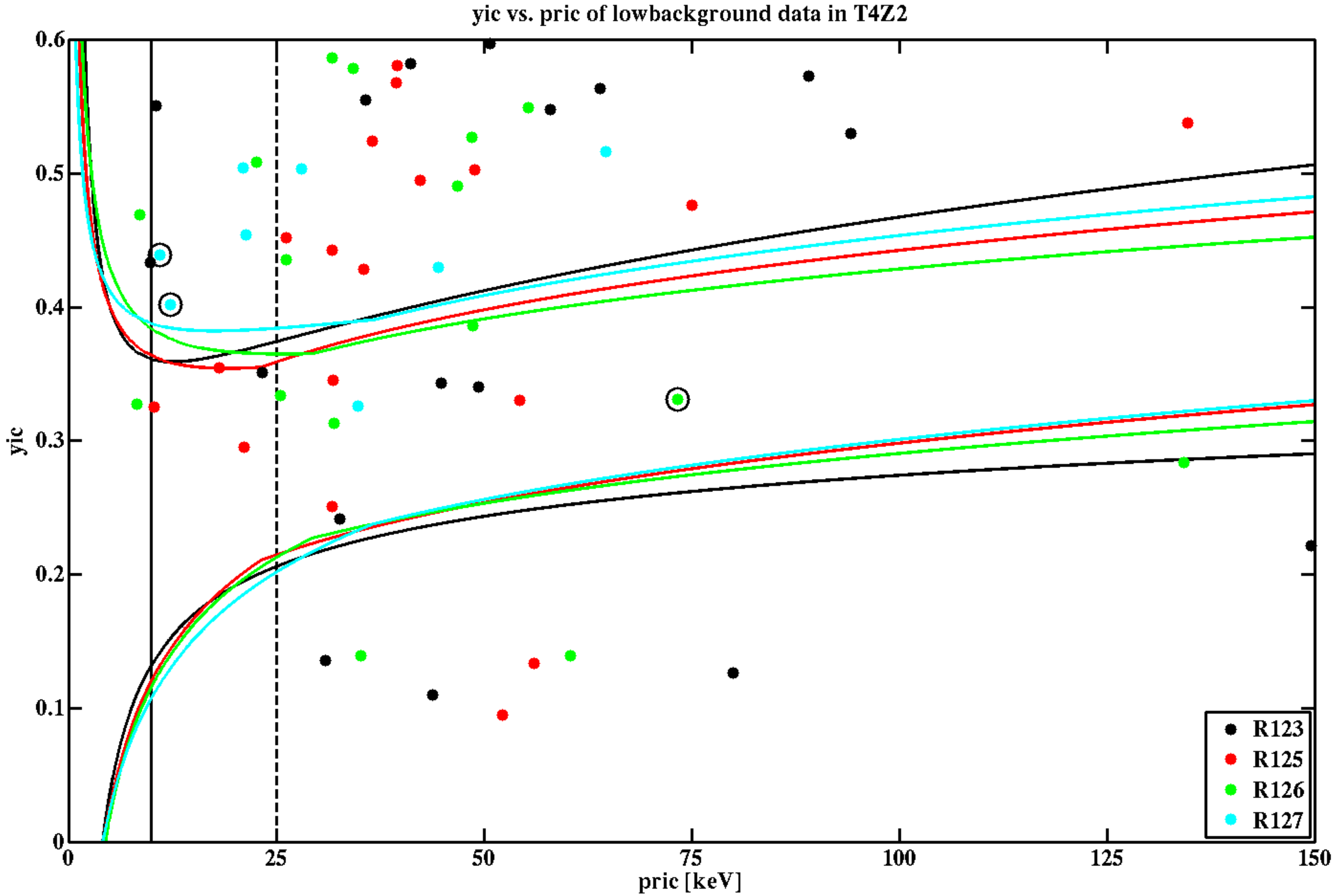


Event 1



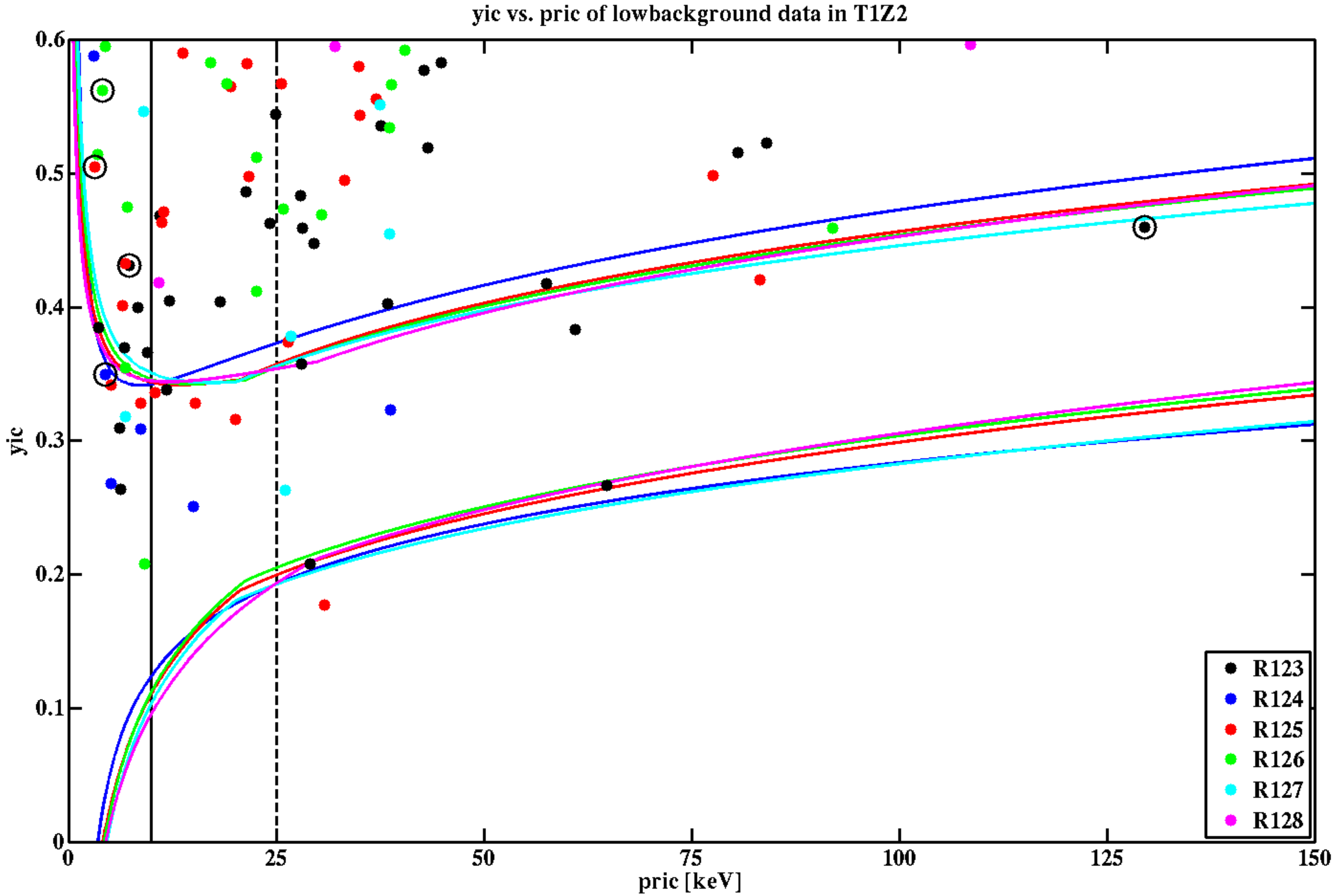
yic vs. pric of lowbackground data in T4Z6
yic
pric [keV]
0
0.1
0.2
0.3
0.4
0.5
0.6
0
25
50
75
100
125
150
R123
R124
R125
R126
R127
R128

Event 2

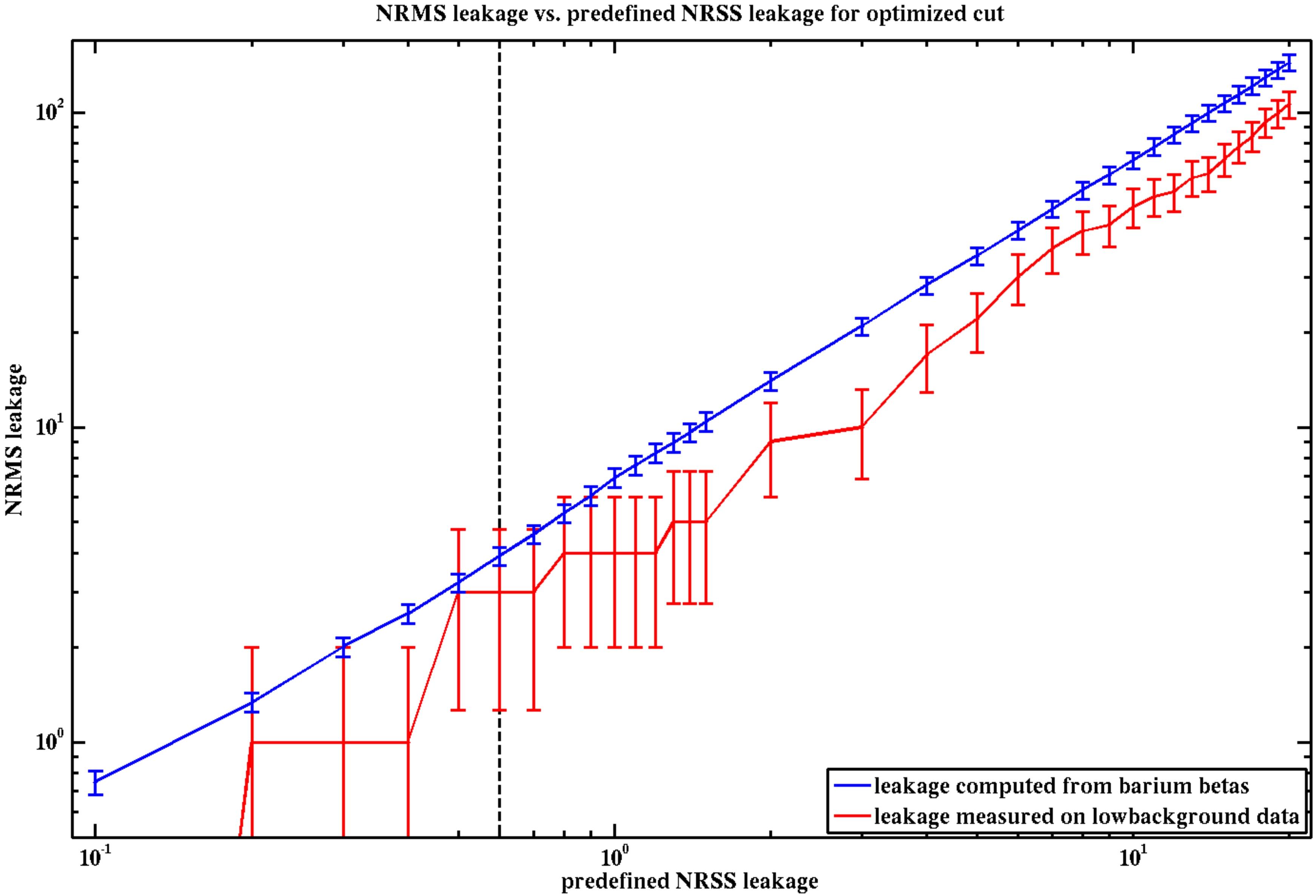


yic vs. pric of lowbackground data in T4Z2
yic
pric [keV]
0.6
0.5
0.4
0.3
0.2
0.1
0
0
25
50
75
100
125
150
R123
R125
R126
R127

Event 3


yic vs. pric of lowbackground data in T1Z2
yic
pric [keV]
0
0.1
0.2
0.3
0.4
0.5
0.6
0
25
50
75
100
125
150
R123
R124
R125
R126
R127
R128

Test timing cuts on NRMS



Check variation of timing cut on NRSS