Study of the double beta decay of ^{76}Ge into excited states of ^{76}Se

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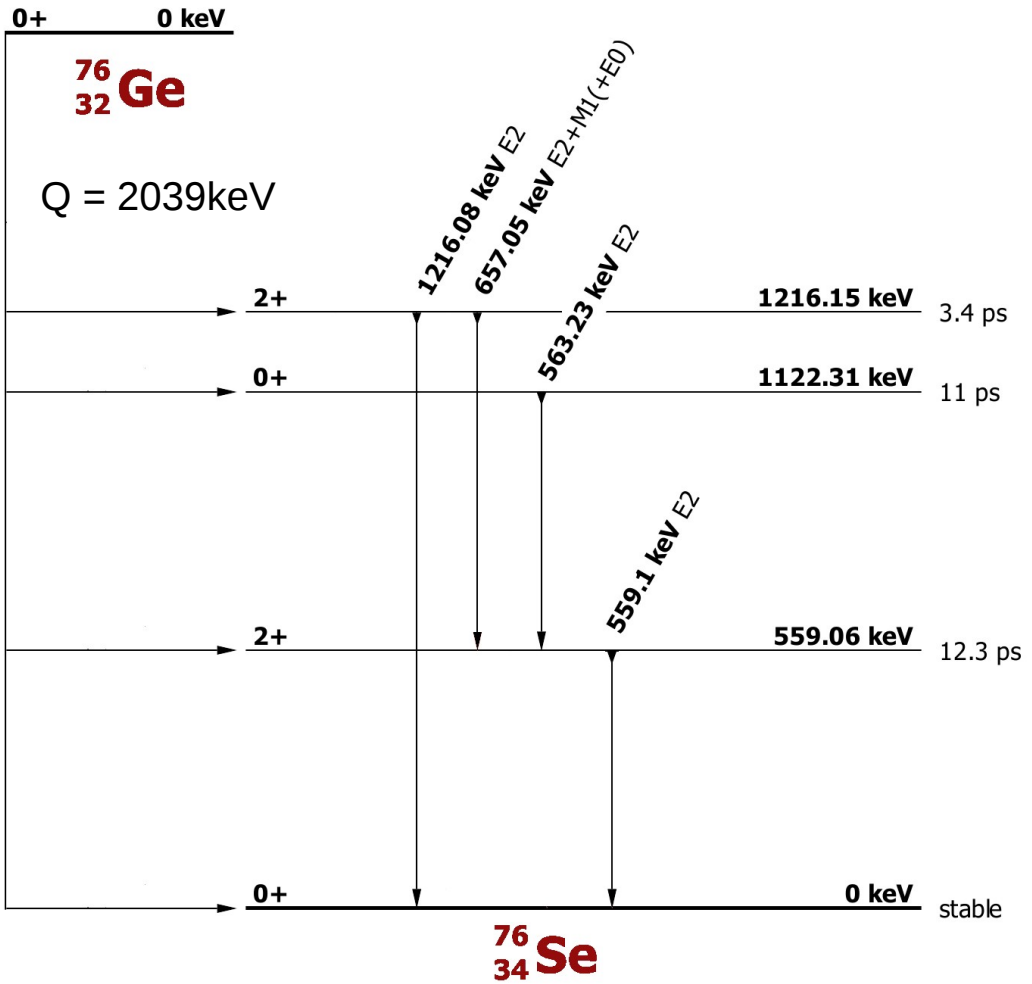
Motivation

- Observation of ββ-decays to excited states offers additional information to the theory of matrix elements

  → Help to define nuclear matrix elements more precisely

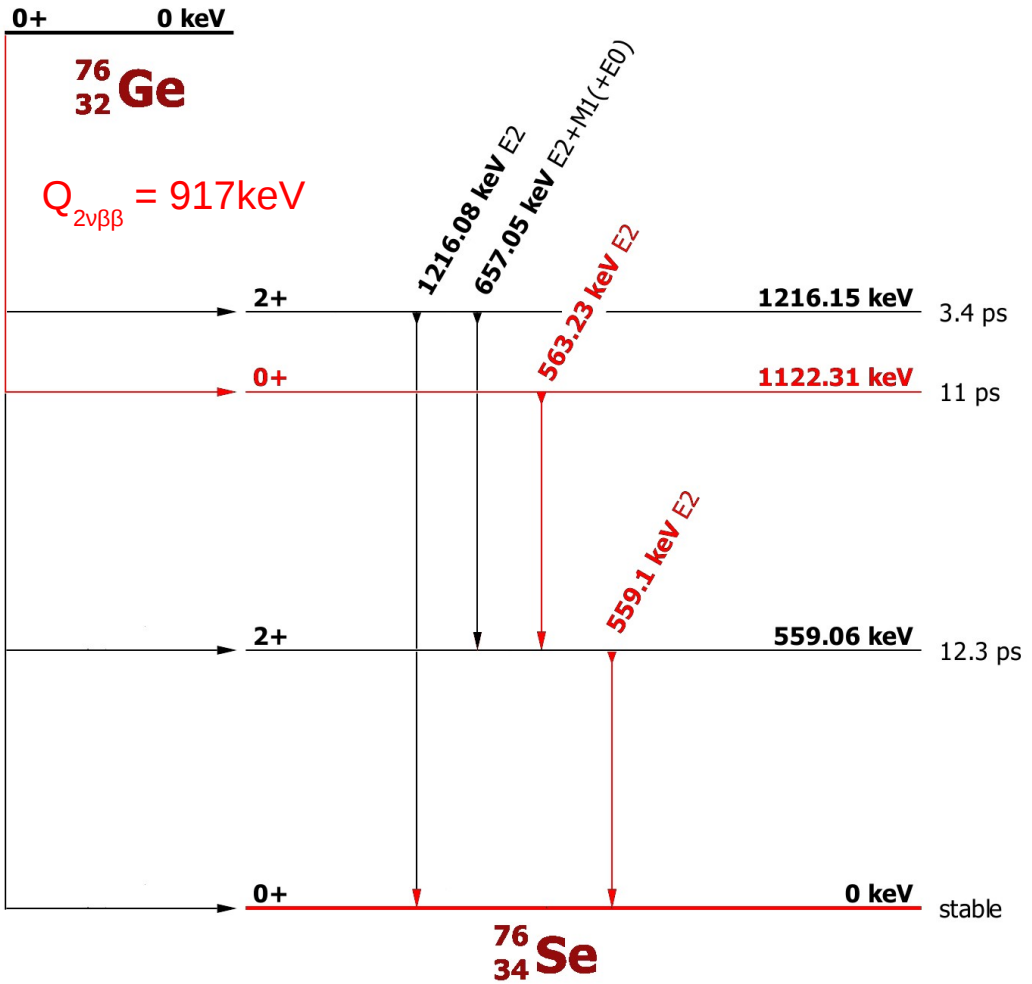
- Detector array suited to detect coincident gammas

Double beta decay to excited states: ^{76}Ge



Double beta decay to excited states: ^{76}Ge

- Dominant decay mode: $0^+ \rightarrow 0_1^+$



Double beta decay to excited states: ^{76}Ge

- Half life predictions:

Decay	$T_{1/2}$ [yr]	Model	Reference
$0^+ \rightarrow 0^+(1122\text{keV})$	$4.0 \cdot 10^{22}$	QRPA	[Nucl. Phys. A 602 (1996) 133]
	$7.5 \cdot 10^{21}$	MCM	[Nucl. Phys. A 575 (1994) 251]
	$4.5 \cdot 10^{22}$	QRPA	[Nucl. Phys. A 602 (1996) 197]
	$1.0..3.1 \cdot 10^{23}$	MCM	[Phys. Rev. C 55, 2314 (1997)]

- Current best limit: $0_0^+ \rightarrow 0_1^+$

$T_{1/2} > 6.2e21$ yr (90% C.L.) [JETP Letters V.72, p.279, 2000]

The data

- “Golden“ dataset
  - Coax + BEGe detectors
  - 11/2011 – 05/2013
  - 2 detector configurations
    - → until 05/2012 w. string 4a: 11 detectors (Coax)
    - → from 07/2012 w. string 4b: 14 detectors (Coax+BEGe)
  - Some detectors are switched on/off inbetween runs
  - Multiplicity breakdown: (Threshold 100keV)

Multiplicity	1	2	3	4	5
#events	820,000	3142	99	2	1

Procedure: Data → $T_{1/2}$

$$T_{1/2} = \frac{\log(2) \cdot \mathcal{E}_{76} \cdot \varepsilon}{N_S}, \qquad \mathcal{E}_{76} = t \cdot \frac{M \cdot f_{76}}{76\mathrm{u}}$$

- N_S … signal counts
- ε … signal efficiency
- $\mathcal{E}_{76}$ … isotopic exposure (atoms·d)
- t … live time:

  count pulser pulses
- $M \cdot f_{76}$ … mass of ^{76}Ge

Procedure: N_S from counting method

- N_{ROI}: number of events in region of interest

  (e.g. gamma energy)

- N_B: number of expected background events in ROI

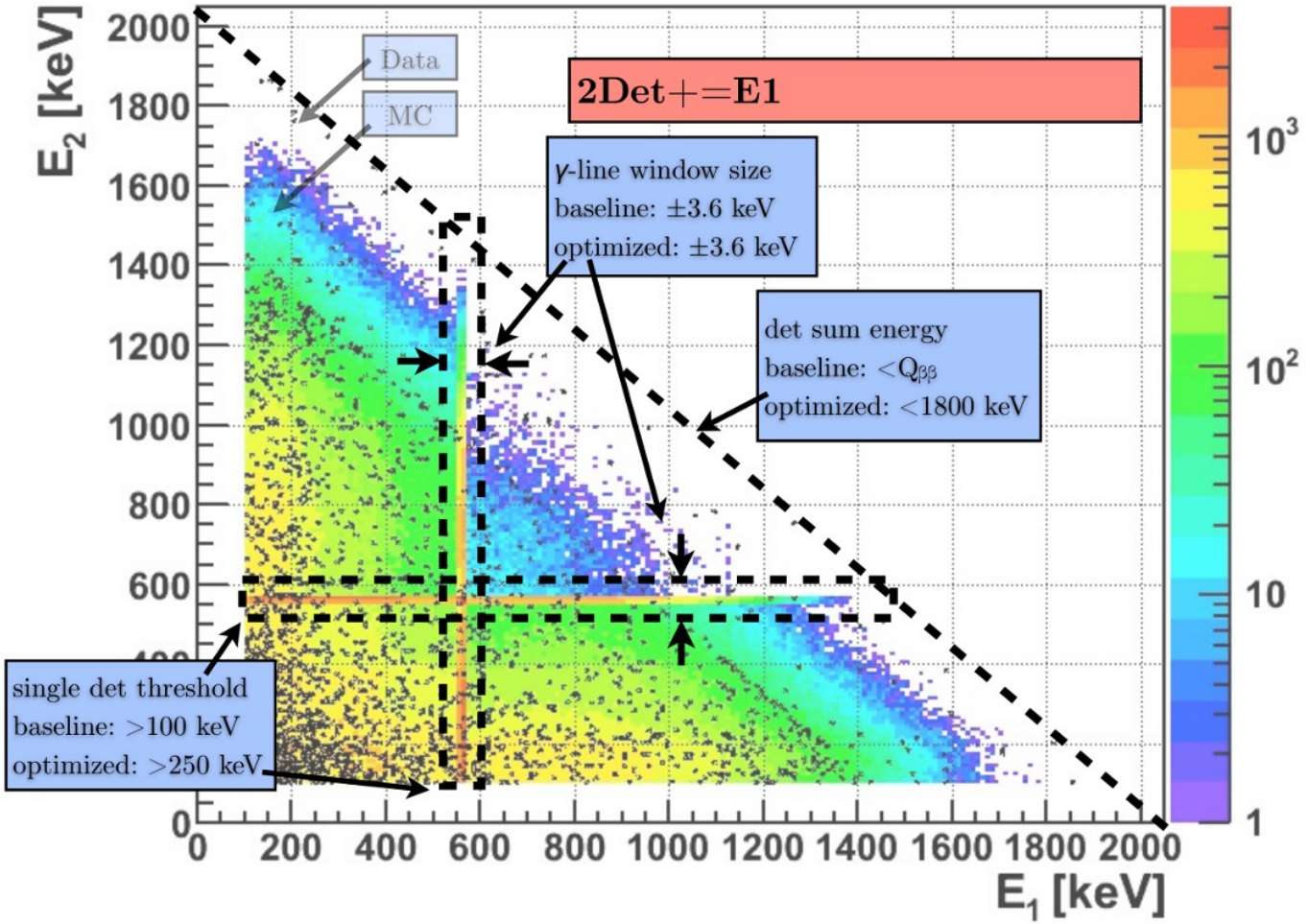
  → estimated from sidebands left and right of ROI

  → sidebands verified with Background Model

- Feldman-Cousins (N_{ROI},N_B) → limits on N_S

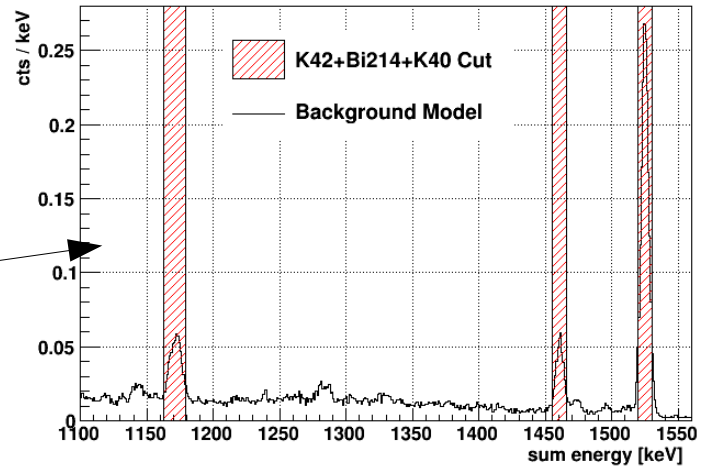
Cuts: $2\nu\beta\beta\ 0_0^+ \rightarrow 0_1^+$

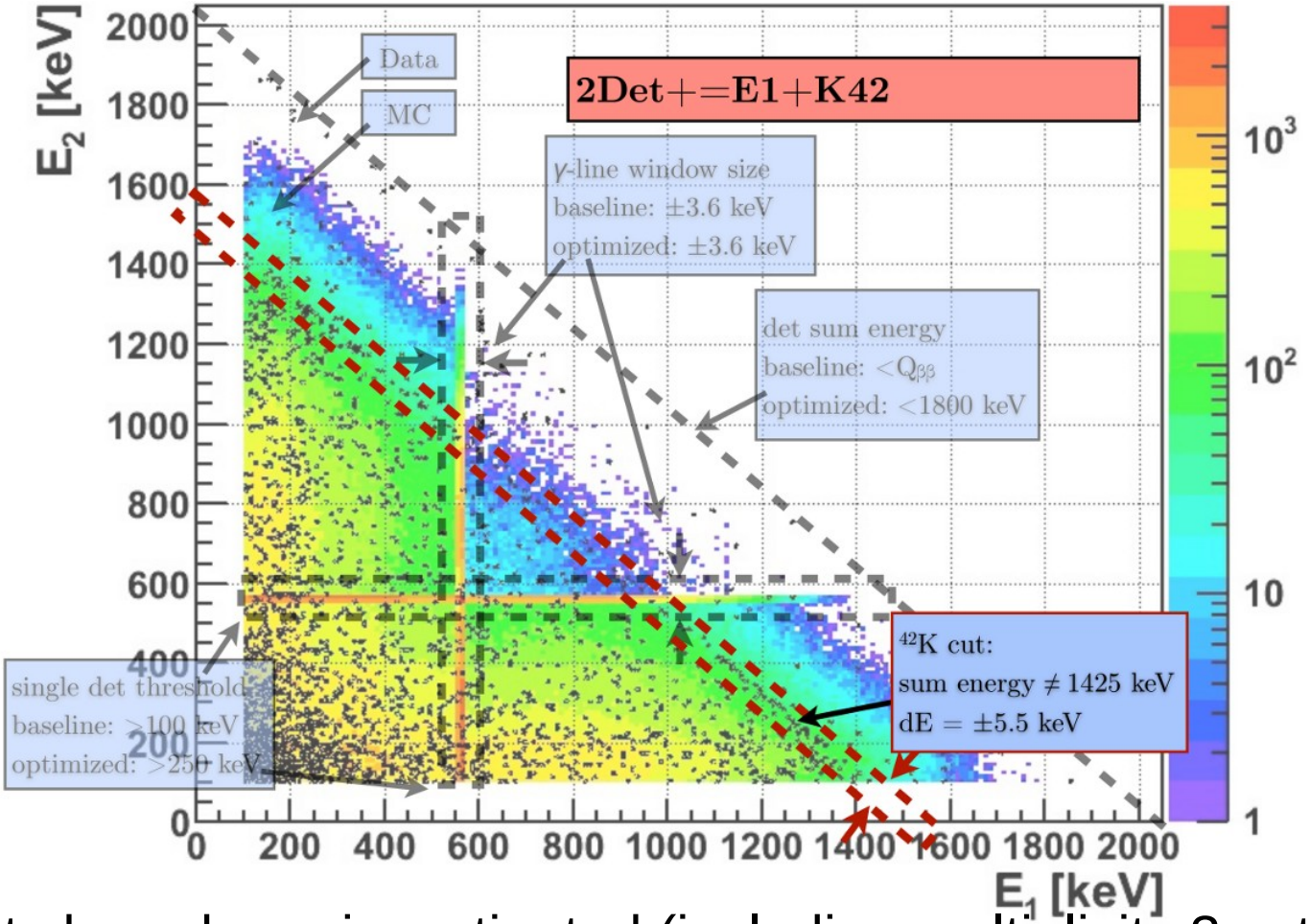
- Base cut: 2Det+=E1 :
  - 2 detectors above threshold
  - 1 detector has one of the gamma energies (559keV or 563keV)



Cuts: $2\nu\beta\beta\ 0_0^+ \rightarrow 0_1^+$

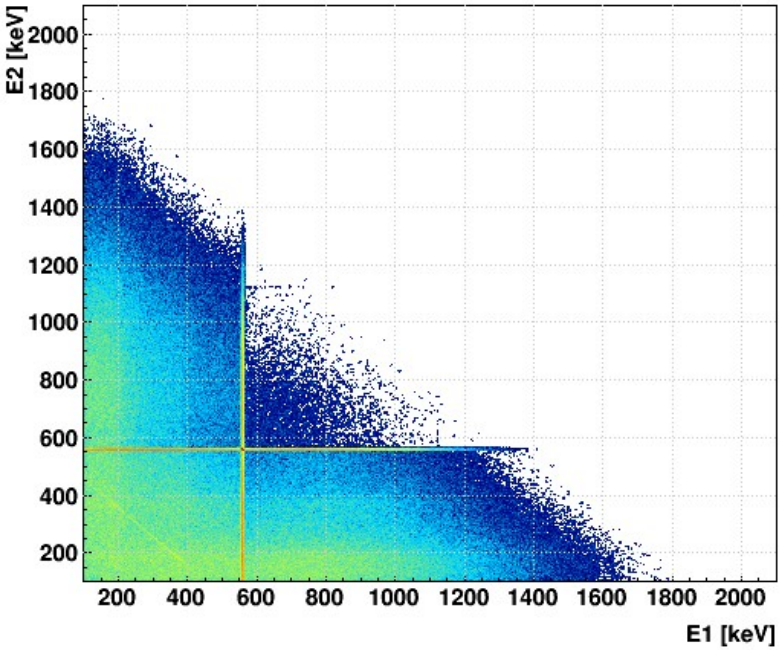
- Two extensions:
  - K42+Bi214+K40 : exclusion of sum energy background lines
  - noGTF : only enriched source detectors

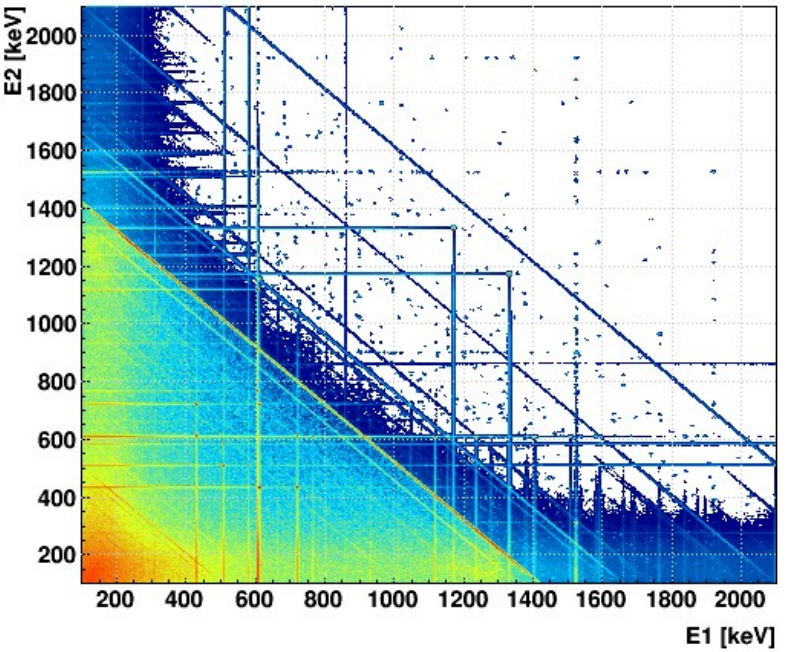




- More cuts have been investigated (including multiplicity 3 cuts)

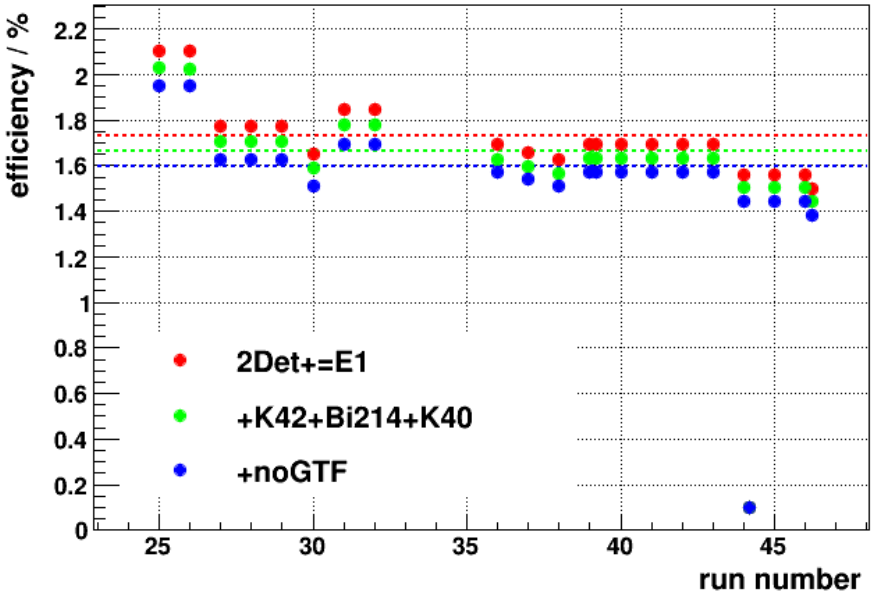
Monte Carlo simulations

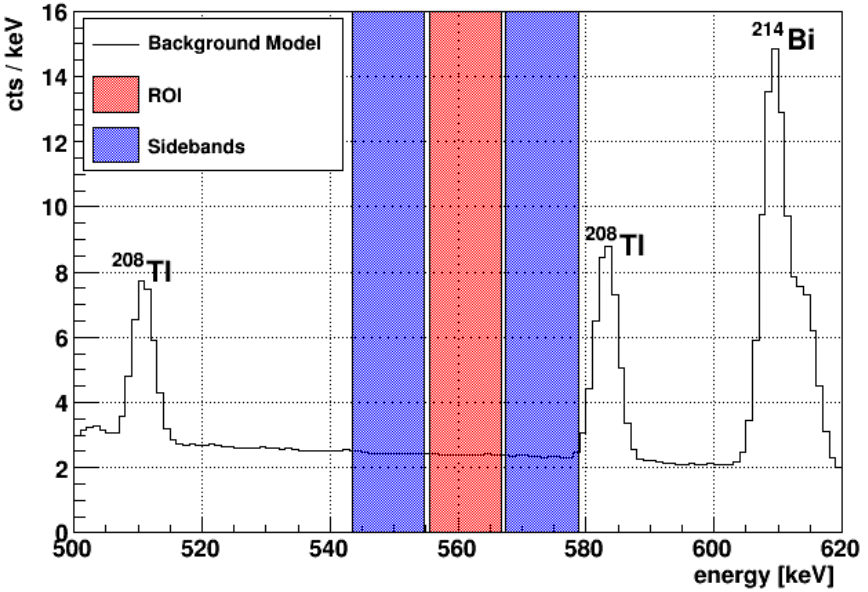




Signal: calculate efficiency ε of signal cuts

Background model: verify sidebands (linear bkg?, no gamma lines?)





Sensitivity optimization

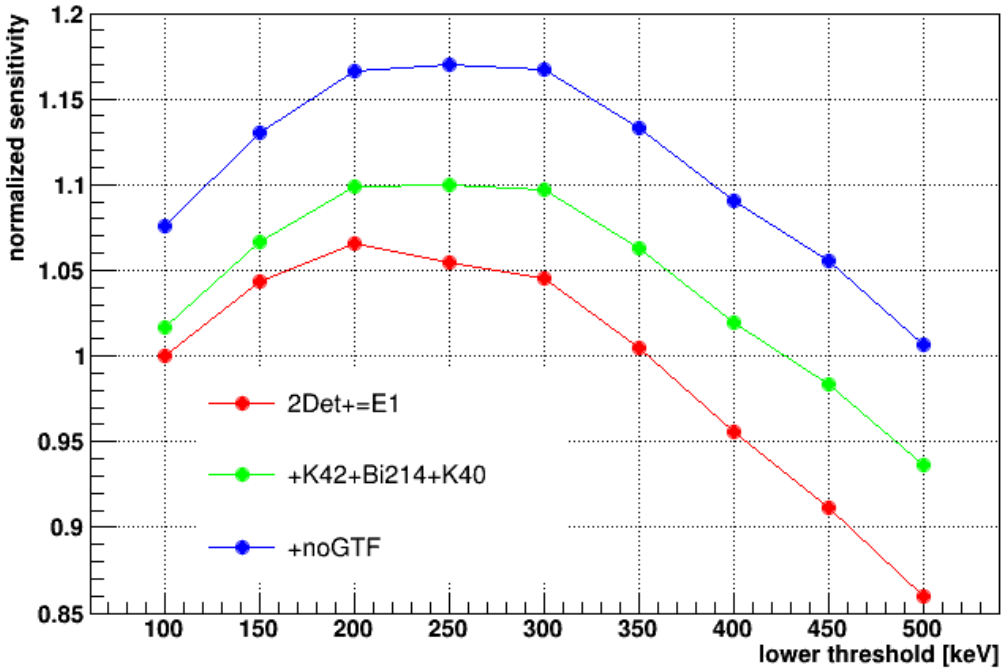
$$Sensitivity \sim \frac{\varepsilon}{\sqrt{N_B^{MC}}}$$

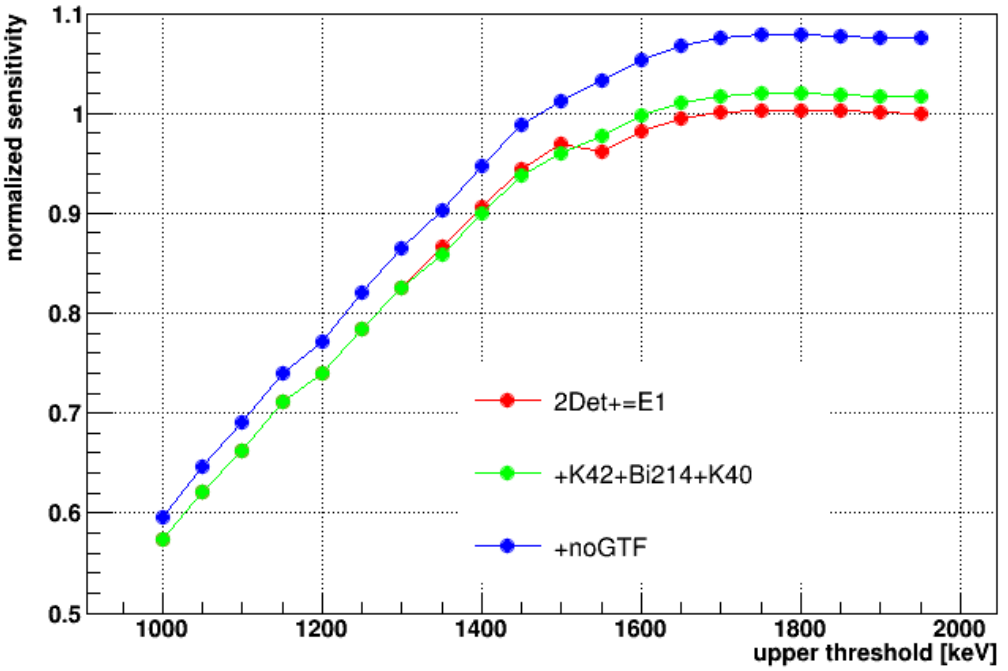
- Optimization entirely based on Monte Carlo data !

- Optimization of:
  - signal cuts
  - counting window width
  - low energy threshold
  - upper sum energy threshold
  - detector pairs

Threshold optimization

- Lower threshold
  - → scanned from 100 keV to 500 keV
  - → optimum 200 keV - 250 keV
- Upper threshold
  - → scanned from 1000 keV to 1950 keV
  - → optimum >1700 keV

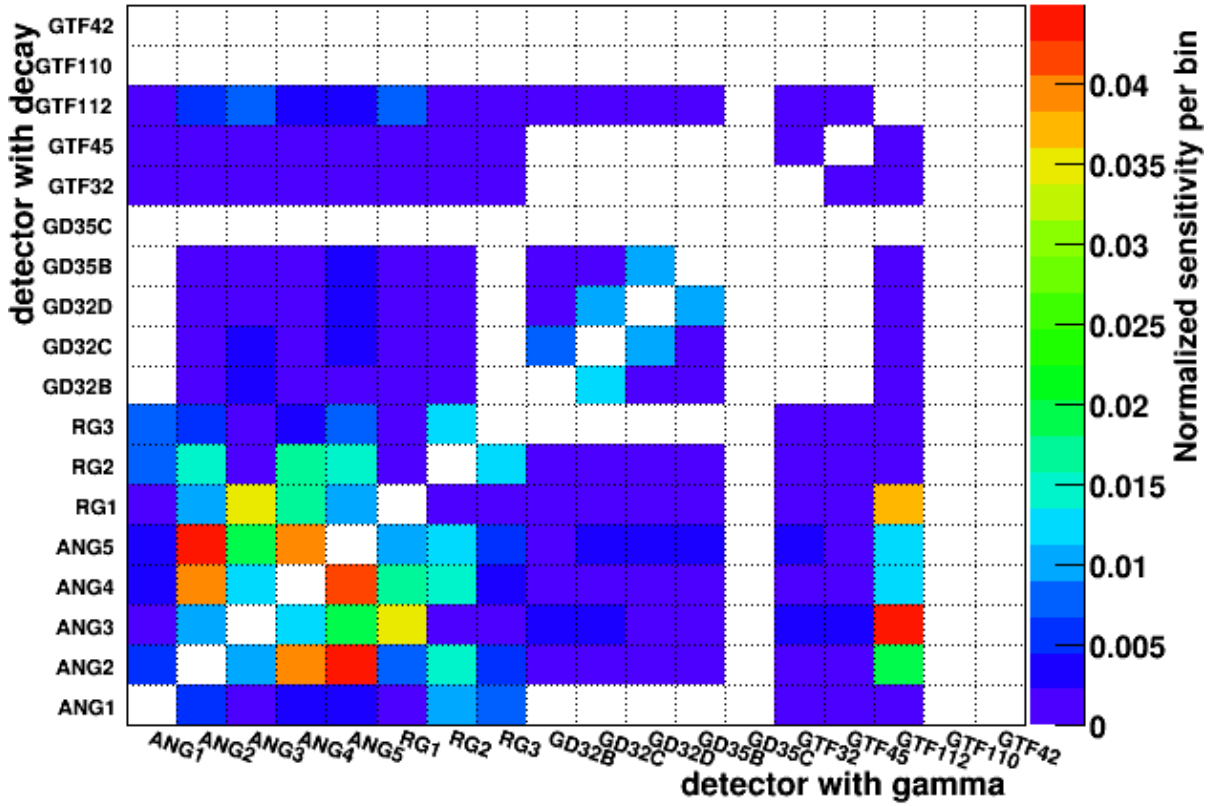


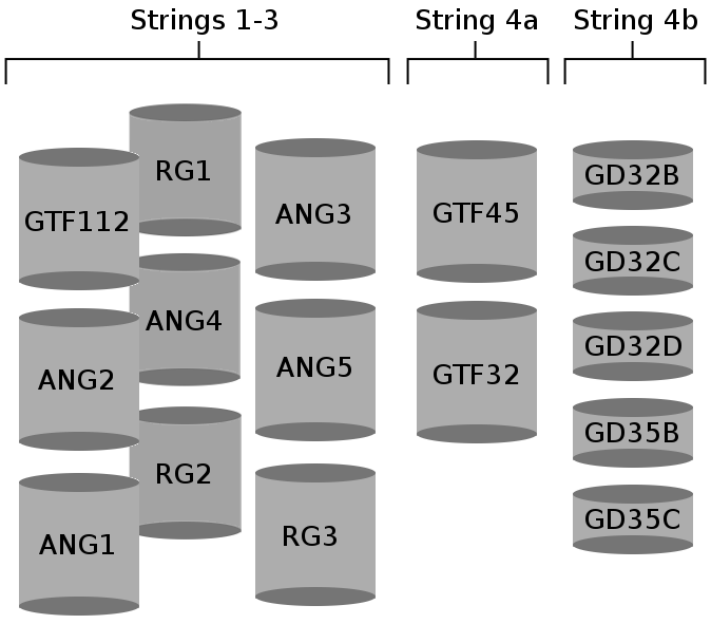


Detector pair optimization

- Looking on sensitivity of each detector pair
- Only accepting pairs with a sensitivity > threshold

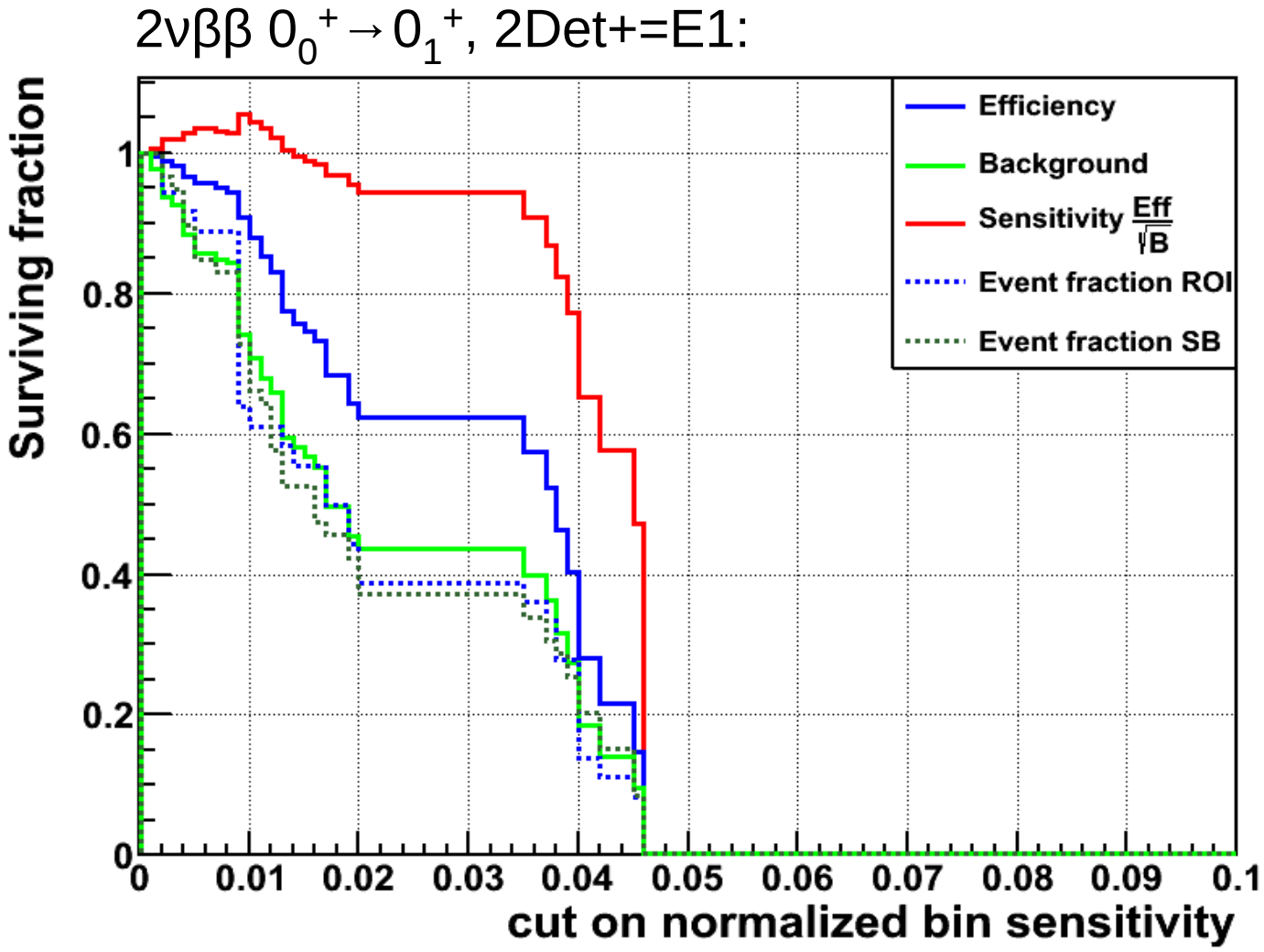
$2\nu\beta\beta\ 0_0^+ \rightarrow 0_1^+$, 2Det+=E1:





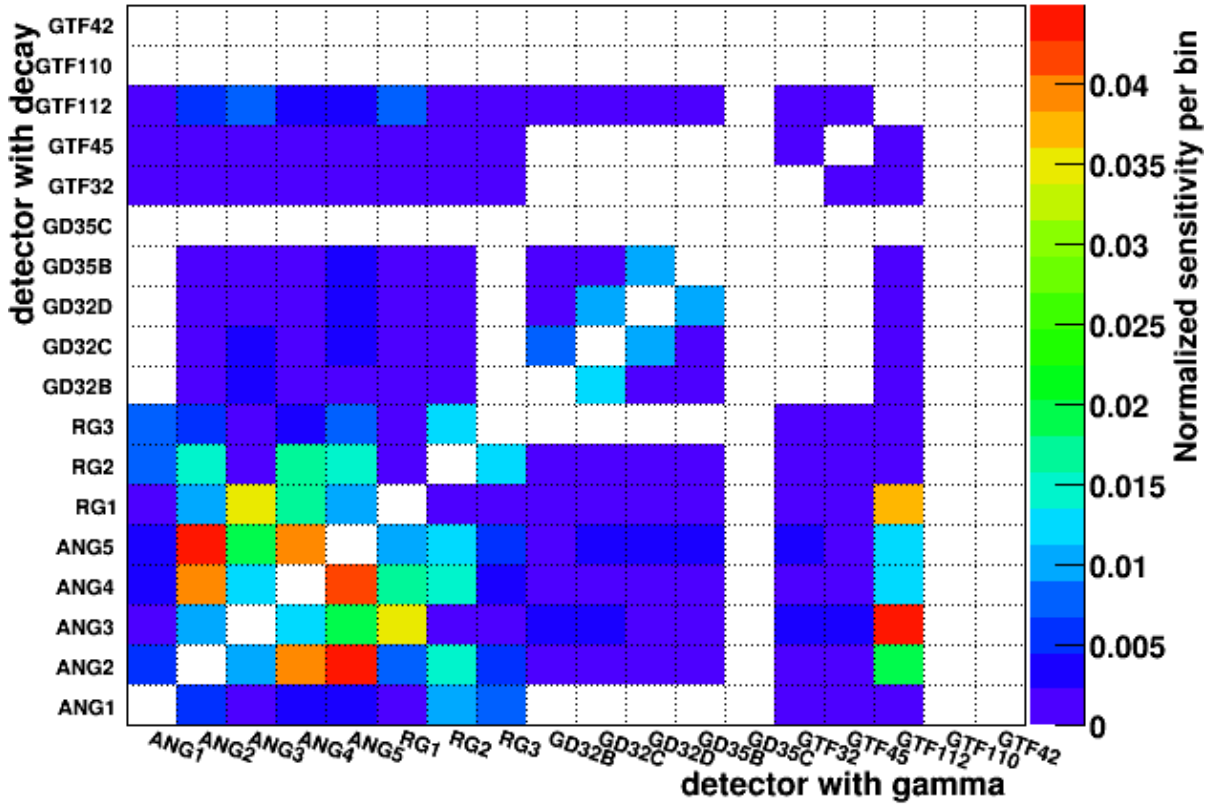
Detector pair optimization

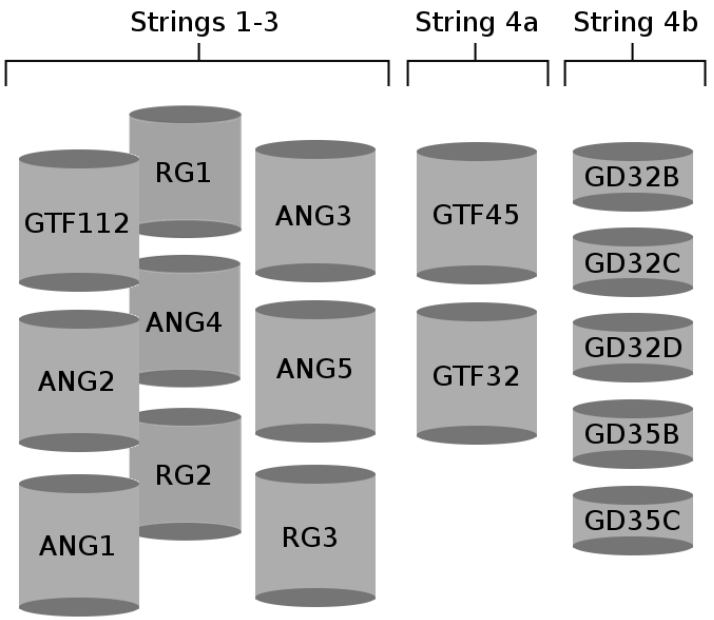
- Scan threshold for best summed sensitivity



Detector pair optimization

$2\nu\beta\beta\ 0_0^+ \rightarrow 0_1^+$, 2Det+=E1:

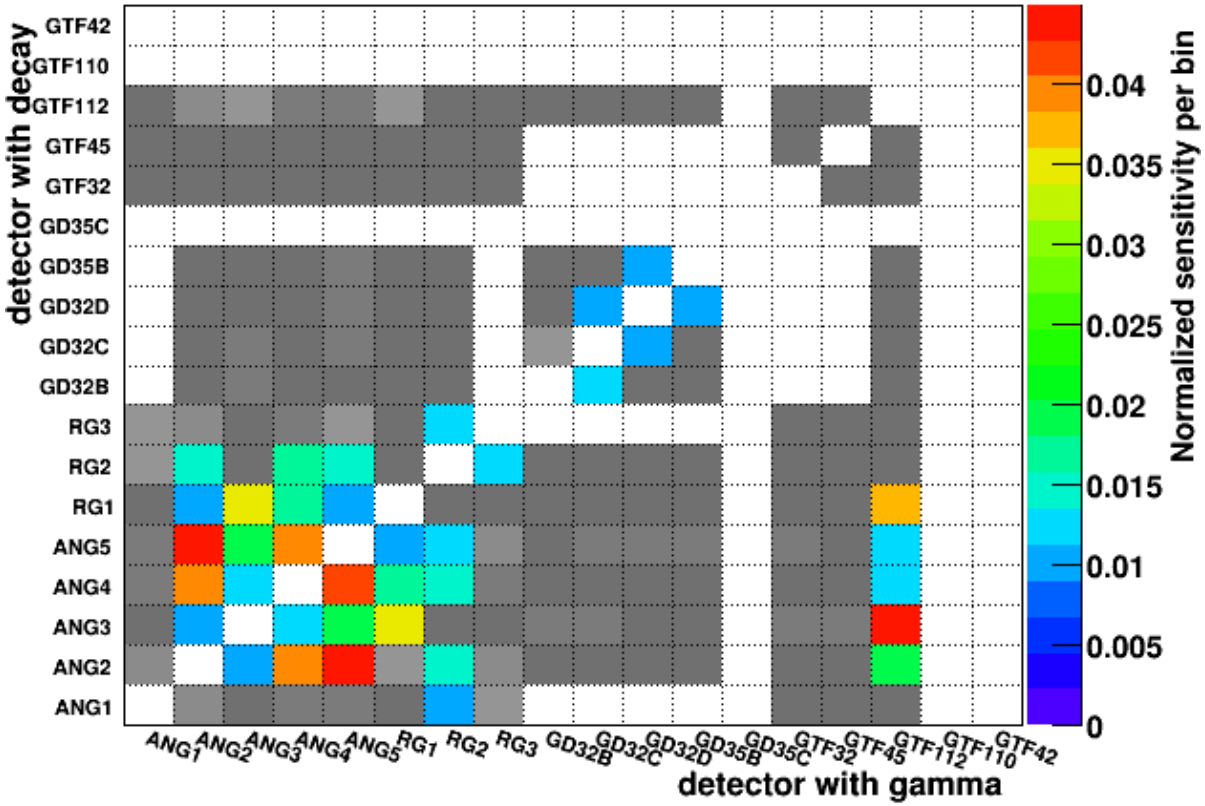


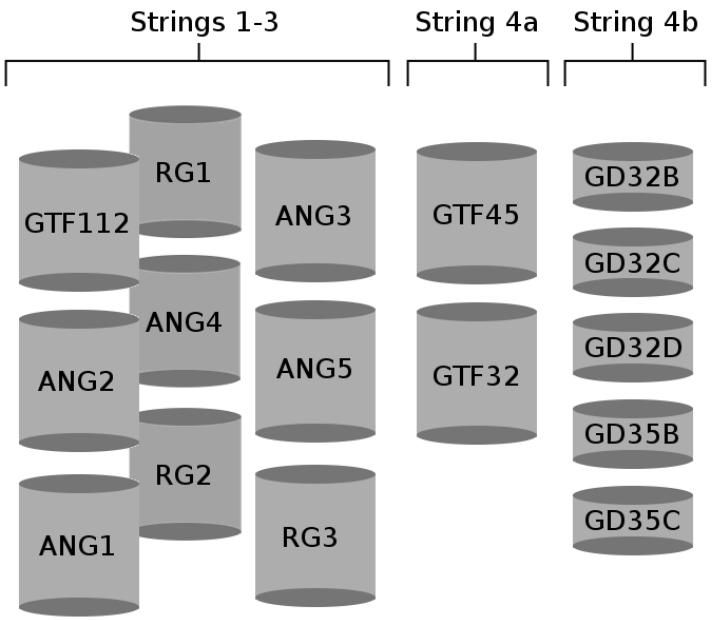


Detector pair optimization

- Cut applied

$2\nu\beta\beta\ 0_0^+ \rightarrow 0_1^+$, 2Det+=E1:





Sensitivities: $2\nu\beta\beta$ $0_0^+ \rightarrow 0_1^+$

- Base:

	Cut	Efficiency	N_B^{SB}(MC)	N_B^{ROI}(MC)	Sensitivity / yr
1	2Det+=E1	1.73%	28.6	28.9	2.15e23
2	+K42+Co60+K40	1.67%	26.2	26.1	2.18e23
3	+NoGTF	1.60%	21.3	21.3	2.31e23

- Optimized:
  - 2Det+=E1+K42+noGTF
  - threshold: 250keV
  - window size: +-3.6keV
  - detector pair optimization

	Cut	Efficiency	N_B^{SB}(MC)	N_B^{ROI}(MC)	Sensitivity / yr
	Optimized	1.39%	12.9	12.8	2.59e23

- Current best limit: $T_{1/2} > 6.2e21$ yr (90% C.L.)
  [JETP Letters V.72, p.279, 2000]

Summary

- Search for 2νββ decay of ^{76}Ge into excited states of ^{76}Se
- Using GERDA coincidence data (Multiplicity 2)
- Signal MC to calculate efficiencies
- Background model to verify sidebands
- Optimization of sensitivity based on MC data
- Optimized sensitivity: 2.59e23 yr ($0_0^+ \rightarrow 0_1^+$) (@90% C.L.)

- Analysis ready to process data
- Other decay modes are analyzed,
  including 0νββ decays to excited states

Thanks