



Background

Methods

Research questions

- Which heart beat detection method performs best in healthy and diseased ECGs?
- Can we improve the detection results by changing the preprocessing steps?
- How much are the results influenced by the presence of cardiac abnormalities?
- Which ECG lead shows the best performance?

12-lead resting ECGs

- A SFB/TR19** study on inflammatory cardiomyopathy (study center Greifswald) n=704, various abnormalities, e.g., 113 AFIB, 66 AVB, 63 LAA, 110 LBBB, 71 LVHREP, 83 NFRA ...
- B Study of Health in Pomerania (SHIP)** includes two individual cohorts with follow-up examinations SHIP-START cohort (START-0: n=3546, START-1: n=3274, START-2: n=2314, START-3: n=1713) SHIP-TREND cohort (TREND-0: n=4386, TREND-1: n=2484)

Course of the experiment

Using open source methods, all ECGs will be preprocessed and beats were annotated by various detection methods in each combination:
ECG × lead × preprocessing method × beat detection method

- Preprocessing** Neurokit2 (neurokit, biosppy, pantompkins1985, hamilton2002, elgendi2010, engzeemod2012), Bandpass filtering (scipy.signal: Butterworth 5th grade, 3–20 Hz; 0.05–42 Hz), Wavelet denoising (pywt: Haar, skimage.restoration: Sym8, db4), Corcodan (in-house, filter-based), CycleGAN (Kiranyaz et al.)
- Beat detection** Neurokit2, py-ecg-detectors, WFDB for Python, Eplimited, ECG2RR, C-LABPL, WTdelineator

Train & Test

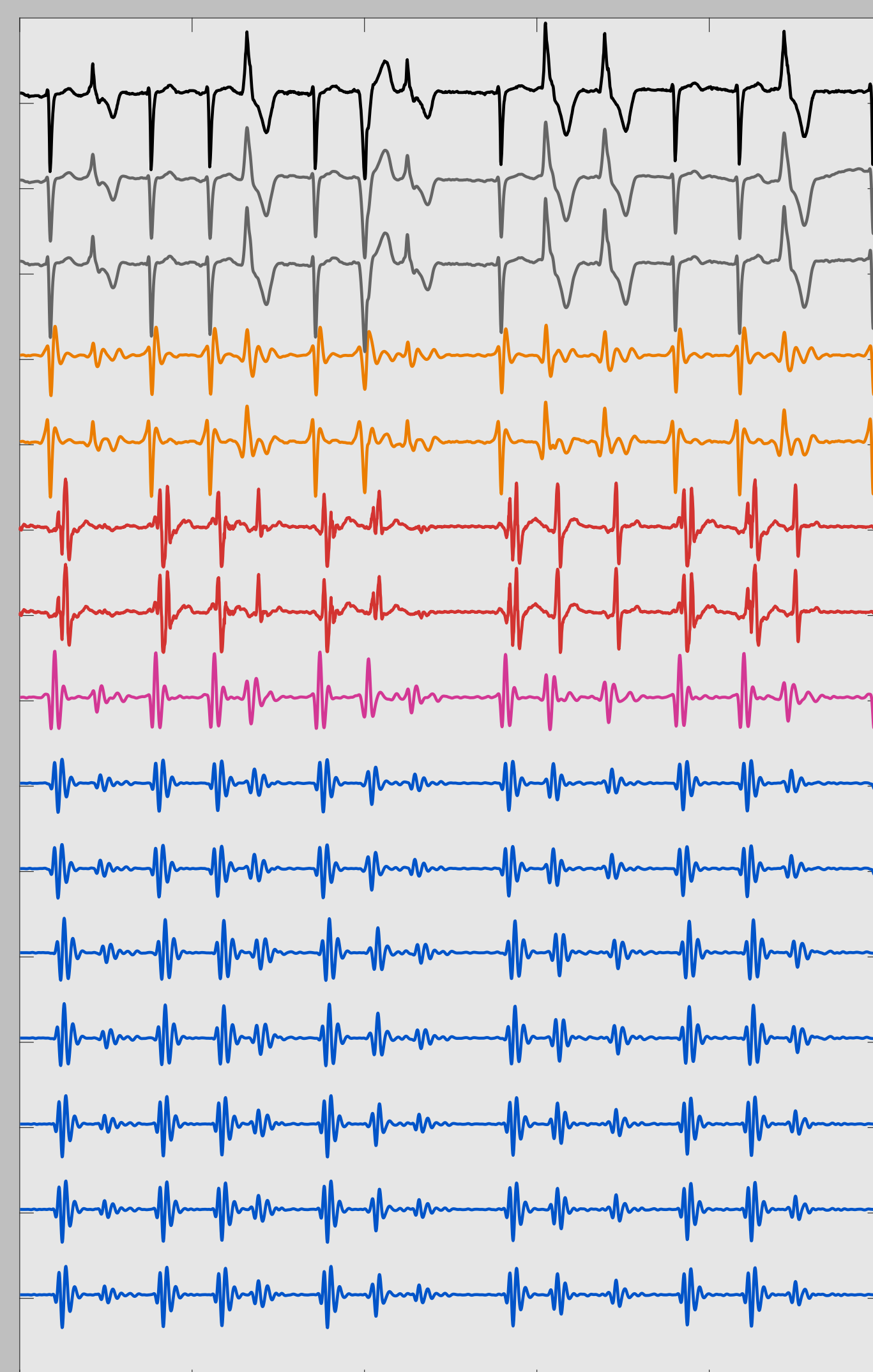
Choosing best combinations:

- Selection** ("Train" n=11,269): 60% of SFB/TR19 + SHIP-START
- Prove stability** ("Test" n=7,152): 40% of SFB/TR19 + SHIP-TREND

Evaluation method

- SFB/TR19: Automated and manually screened annotations
- SHIP: Generation of silver standard using all generated annotations
- Pairwise comparison of annotations with the reference at 10 ms, 25 ms, 50 ms, 100 ms tolerance with and without correction of systematic shifts: counting FN, FP, TP + multiple matches within $1 \cdot f_s \leq t \leq 9 \cdot f_s$.
- Computation of average sensitivity and positive predictive value

Preprocessing

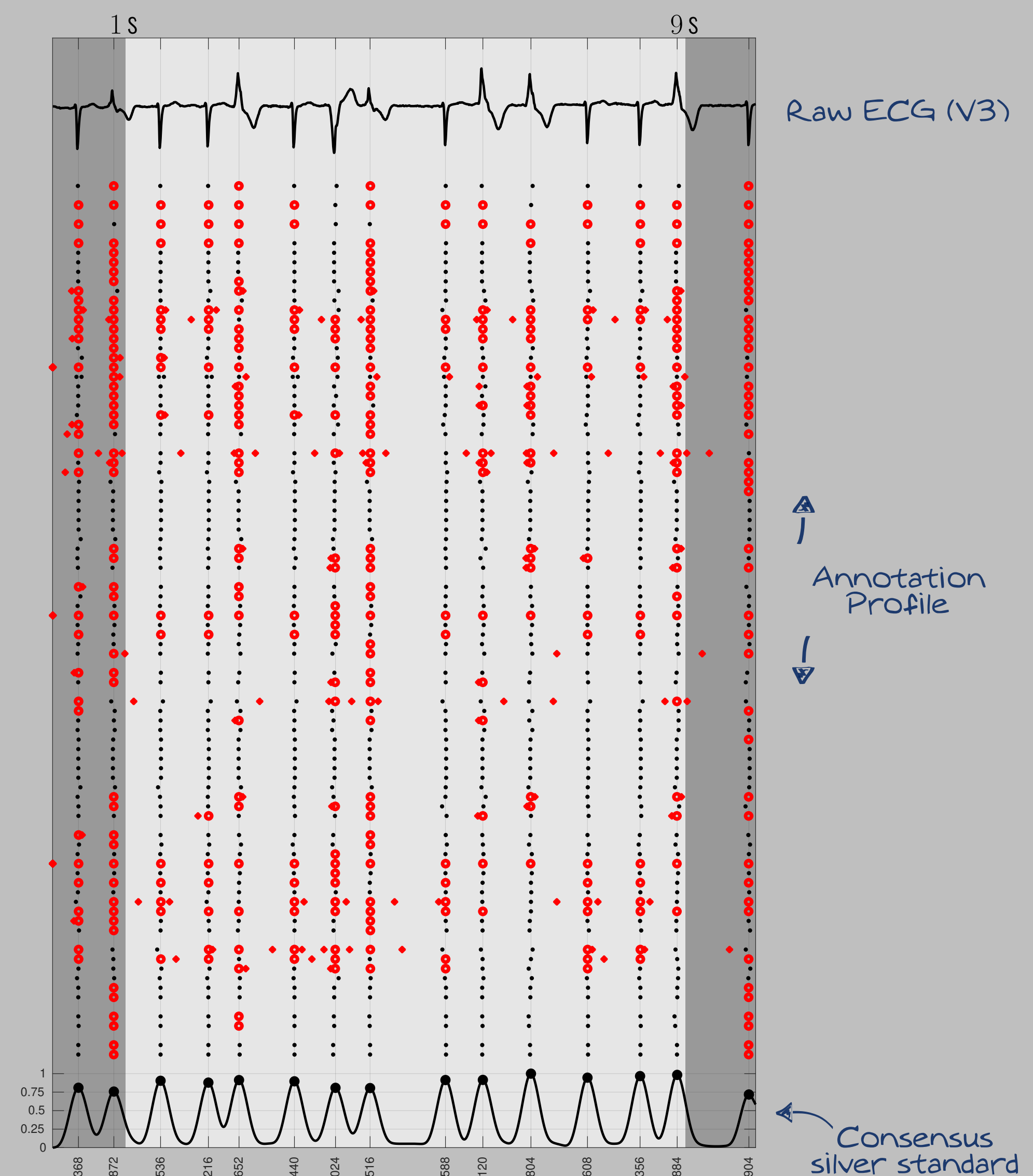


- Raw ECG
- Neurokit
- Corcodan
- PanTompkins1985
- BioSPPy
- CycleGAN_scaled
- CycleGAN
- Hamilton2002
- EngZee_mod2012
- Elgendi2010
- Butter 3-20Hz
- Butter .05-42Hz
- Symlets8
- Haar
- Daubechies4

Libraries and methods for heart beat detection

- Neurokit2**
 - Pan-Tompkins1985
 - Nabian2018 Zong2003
 - Gamboa2008 Martinez2003
 - Rodriguez2021 BioSPPy
 - Kalidas2017 Neurokit
 - Christov2004 Elgendi2010
 - ProMac Hamilton2002
 - Engelse-Zeelenberg2012
- py-ecg-detectors**
 - Hamilton wqrs
 - Elgendi Christov
 - Pan-Tompkins
 - Engelse-Zeelenberg
 - Kalidas FIR matched filter
- WFDB**
 - XQRS XQRS+learn
 - gqrs_detect
 - xqrs_detect+learn
 - xqrs_detect
- Eplimited**
 - eplimited
 - factor=1000
 - quantile-scaled
- ECG2RR**
 - ecg2rr
 - ecg2rr (thr=300ms)
- Others**
 - C-LABPL
 - WTdelineator

Beat detection



Performance

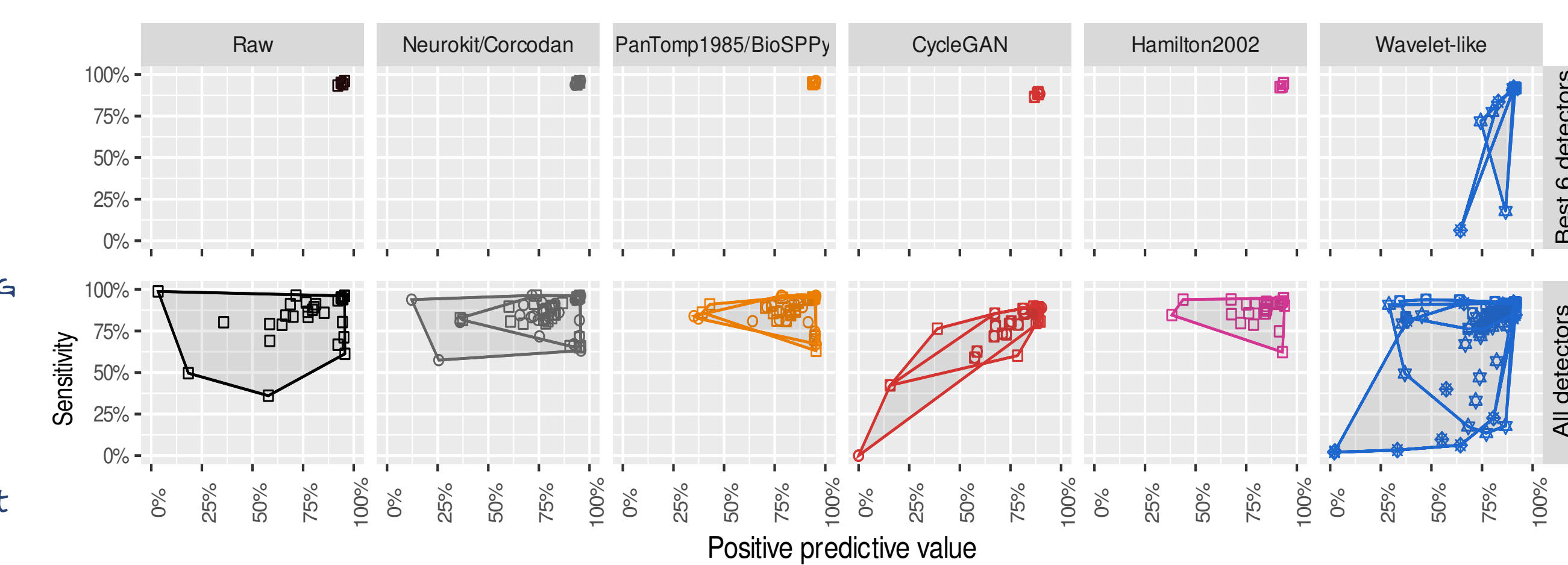
Summary

Best 6 annotators with best 2 preprocessing methods

Preprocessing	Detector	Healthy cohort		Diseased cohort	
		Train SHIP-START PPV/Sens	Test SHIP-TREND PPV/Sens	Train 60% SFB PPV/Sens	Test 40% SFB PPV/Sens
raw	eplimited quantile-scaled	.956 / .962	.972 / .979	.930 / .943	.931 / .941
corcodan		.957 / .963	.975 / .983	.932 / .946	.932 / .942
biosppy		.955 / .962	.973 / .983	.920 / .933	.918 / .928
raw	nk2::kalidas2017	.930 / .940	.967 / .970	.715 / .784	.713 / .778
biosppy		.954 / .953	.975 / .974	.893 / .898	.872 / .875
neurokit		.955 / .954	.975 / .974	.893 / .898	.876 / .879
raw	wfdb4::xqrs	.941 / .953	.975 / .971	.854 / .874	.842 / .860
corcodan		.941 / .953	.975 / .971	.854 / .874	.843 / .860
neurokit		.941 / .954	.975 / .964	.865 / .884	.852 / .868
raw	nk2::neurokit	.954 / .950	.973 / .972	.779 / .738	.768 / .730
corcodan		.954 / .952	.973 / .974	.795 / .765	.786 / .756
biosppy		.948 / .952	.971 / .974	.796 / .802	.780 / .784
raw	wfdb4::xqrs_detect+learn	.941 / .953	.965 / .976	.854 / .874	.842 / .860
corcodan		.941 / .953	.965 / .975	.854 / .874	.843 / .860
neurokit		.941 / .954	.964 / .975	.865 / .883	.852 / .868
raw	wfdb4::xqrs+learn	.941 / .953	.965 / .975	.854 / .874	.842 / .860
corcodan		.941 / .953	.964 / .975	.854 / .874	.843 / .860
neurokit		.941 / .954	.964 / .975	.865 / .884	.852 / .868

PPV set to 0% if no beat was detected; measures at 50 ms tolerance first averaged across leads then averaged across recordings.

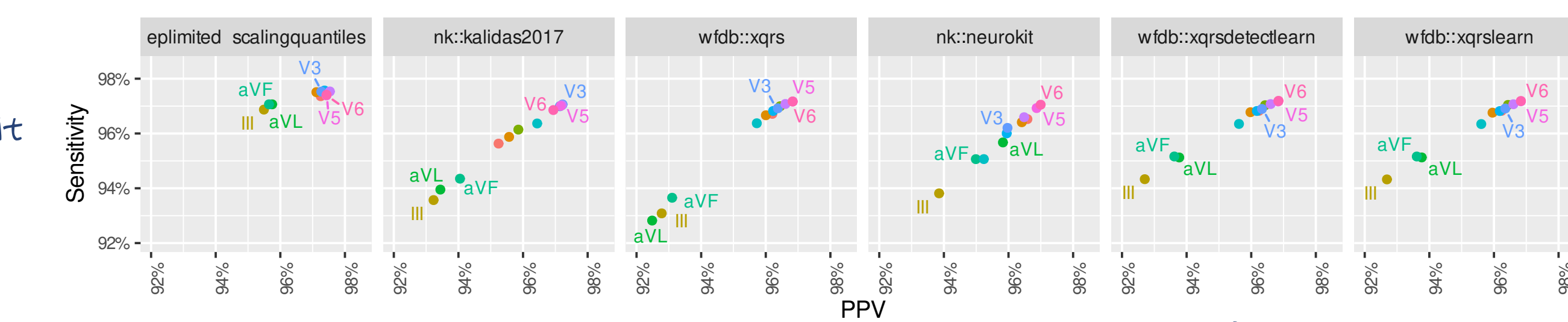
Preprocess - do or don't?



Eplimited is outperforming others

Massive improvement

Which ECG lead if you have to choose?



Averaged across {raw, corcodan, biosppy, neurokit}

