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# **PhyPraKit Documentation**

***Release 1.1.3***

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## ABOUT

**PhyPraKit** is a collection of python modules for data visualisation and analysis in experimental laboratory courses in physics, in use at the faculty of physics at Karlsruhe Institute of Technology (KIT). As the modules are intended primarily for use by undergraduate students in Germany, the documentation is partly in German language, in particular the description of the examples.

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A pdf version of this documentation is available here: [PhyPraKit.pdf](#).

## 1.1 Installation:

To use PhyPraKit, it is sufficient to place the the directory *PhyPraKit* and all the files in it in the same directory as the python scripts importing it.

Installation via *pip* is also supported. After Downloading, execute:

```
pip install --user .
```

in the main directory of the *PhyPraKit* package (where *setup.py* is located) to install in user space.

The installation *whl*-package in the subdirectory *dist* may also be used:

```
pip install --user --no-cache PhyPraKit<version>.whl
```

Installation via the PyPi Python Package Index is also available, simply execute:

```
pip install --user PhyPraKit
```

### German Description:

**PhyPraKit** ist eine Sammlung nützlicher Funktionen in der Sprache *Python* ( $\geq 3.6$ , die meisten Module laufen auch noch mit der inzwischen veralteten Version 2.7) zum Aufnehmen, zur Bearbeitung, Visualisierung und Auswertung von Daten in den physikalischen Praktika. Die Anwendung der verschiedenen Funktionen des Pakets werden jeweils durch Beispiele illustriert.





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## VISUALISATION AND ANALYSIS OF MEASUREMENT DATA

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Methods for recording, processing, visualization and analysis of measurement data are required in all laboratory courses in Physics.

This collection of tools in the package *PhyPraKit* contains functions for reading data from various sources, for data visualization, signal processing and statistical data analysis and model fitting as well as tools for generation of simulated data. Emphasis was put on simple implementations, illustrating the principles of the underlining coding.

The class *mFit* in the module *phyFit* offers a light-weight implementation for fitting model functions to data with uncorrelated and/or correlated absolute and/or relative uncertainties in ordinate and/or abscissa directions. For such complex forms of uncertainties, there are hardly any easy-to-use program packages. Most of the existing applications use presets aiming at providing a parametrization of measurement data, whereby the validity of the parametrization is assumed and the parameter uncertainties are scaled so that the data is well described. *PhyPraKit* offers adapted interfaces to the fit modules in the package *scipy* (*optimize.curve\_fit* and *ODR*) to perform fits with a test of the validity of the hypothesis. *PhyPraKit* also contains a simplified interface to the very function-rich fitting package *kafé2* (or the outdated previous version *kafé*).

### German: Darstellung und Auswertung von Messdaten

In allen Praktika zur Physik werden Methoden zur Aufnahme, Bearbeitung, Darstellung und Auswertung von Messdaten benötigt.

Die vorliegende Sammlung im Paket *PhyPraKit* enthält Funktionen zum Einlesen von Daten aus diversen Quellen, zur Datenvisualisierung, Signalbearbeitung und zur statistischen Datenauswertung und Modellanpassung sowie Werkzeuge zur Erzeugung simulierter Daten. Dabei wurde absichtlich Wert auf eine einfache, die Prinzipien unterstreichende Codierung gelegt und nicht der möglichst effizienten bzw. allgemeinsten Implementierung der Vorzug gegeben.

Das Modul *phyFit* bietet mit der Klasse *mnFit* eine schlanke Implementierung zur Anpassung von Modellfunktionen an Daten, die mit unkorrelierten und/oder korrelierten absoluten und/oder relativen Unsicherheiten in Ordinaten- und/oder Abszissenrichtung behaftet sind. Für solche in der Physik häufig auftretenden komplexen Formen von Unsicherheiten gibt es kaum andere, einfach zu verwendende Programmpakete. Andere Pakete sind meist als Voreinstellung auf die Parametrisierung von Messdaten ausgelegt, wobei die Parameterunsicherheiten unter Annahme der Gültigkeit der Parametrisierung so skaliert werden, dass die Daten gut repräsentiert werden. *PhyPraKit* bietet entsprechend angepasste Interfaces zu den Fitmodulen im Paket *scipy* (*optimize.curve\_fit* und *ODR*), um Anpassungen mit Test der Gültigkeit der Modellhypothese durchzuführen. *PhyPraKit* enthält ebenfalls ein vereinfachtes Interface zum sehr funktionsreichen Anpassungspaket *kafé2* (oder zur mittlerweile veralteten Vorängerversion *kafé*).

In der Vorlesung “Computergestützte Datenauswertung” an der Fakultät für Physik am Karlsruher Institut für Physik (<http://www.ekp.kit.edu/~quast/CgDA>) werden die in *PhyPraKit* verwendeten Methoden eingeführt und beschrieben. Hinweise zur Installation der empfohlenen Software finden sich unter den Links <http://www.ekp.kit.edu/~quast/CgDA/CgDA-SoftwareInstallation.html> und <http://www.ekp.kit.edu/~quast/CgDA/CgDA-SoftwareInstallation.pdf>

Speziell für das “Praktikum zur klassischen Physik” am KIT gibt es eine kurze Einführung in die statistischen Methoden und Werkzeuge ([http://www.ekp.kit.edu/~quast/CgDA/PhysPrakt/CgDA\\_APraktikum.pdf](http://www.ekp.kit.edu/~quast/CgDA/PhysPrakt/CgDA_APraktikum.pdf)).

## DOKUMENTATION DER BEISPIELE

`PhyPraKit.py` ist ein Paket mit nützlichen Hilfsfunktionen zum import in eigene Beispiele mittels:

```
import PhyPraKit as ppk
```

oder:

```
from PhyPraKit import ...
```

**PhyPraKit** enthält folgende **Funktionen**:

1. Daten-Ein und -Ausgabe
  - readColumnData() Daten und Meta-Daten aus Textdatei lesen
  - readCSV() Daten im csv-Format aus Datei mit Header lesen
  - readtxt() Daten im Text-Format aus Datei mit Header lesen
  - readPicoScope() mit PicoScope exportierte Daten einlesen
  - readCassy() mit CASSY im .txt-Format exportierte Dateien einlesen
  - labxParser() mit CASSY im .labx-Format exportierte Dateien einlesen
  - writeCSV() Daten csv-Format schreiben (optional mit Header)
  - writeTexTable() Daten als LaTeX-Tabelle exportieren
  - round\_to\_error() Runden von Daten mit Präzision wie Unsicherheit
  - ustring() korrekt gerundete Werte  $v \pm u$  als Text; alternativ: der Datentyp `ufloat(v, u)` im Paket `uncertainties` unterstützt die korrekte Ausgabe von Werten  $v$  mit Unsicherheiten  $u$ .
2. Signalprozessierung:
  - offsetFilter() Abziehen eines off-sets
  - meanFilter() gleitender Mittelwert zur Glättung
  - resample() Mitteln über  $n$  Datenwerte
  - simplePeakfinder() Auffinden von Maxima (Peaks) und Minima (*Empfehlung: convolutionPeakfinder nutzen*)
  - convolutionPeakfinder() Finden von Maxima
  - convolutionEdgefinder() Finden von Kanten
  - Fourier\_fft() schnelle Fourier-Transformation (FFT)
  - FourierSpectrum() Fourier-Transformation (*langsam, vorzugsweise FFT-Version nutzen*)

- autocorrelate() Autokorrelation eines Signals

3. Statistik:

- wmean() Berechnen des gewichteten Mittelwerts
- BuildCovarianceMatrix() Kovarianzmatrix aus Einzelunsicherheiten
- Cov2Cor() Konversion Kovarianzmatrix -> Korrelationsmatrix
- Cor2Cov() Konversion Korrelationsmatrix + Unsicherheiten -> Kovarianzmatrix
- chi2prob() Berechnung der  $\chi^2$ -Wahrscheinlichkeit
- propagatedError() Numerische Fehlerfortpflanzung; Hinweis: der Datentyp *ufloat*(*v*, *u*) im Paket *uncertainties* unterstützt Funktionen von Werten *v* mit Unsicherheiten *u* und die korrekte Fehlerfortpflanzung
- getModelError() Numerische Fehlerfortpflanzung für parameterabhängige Funktionswerte

4. Histogramm:

- barstat() statistisch Information aus Histogramm (Mittelwert, Standardabweichung, Unsicherheit des Mittelwerts)
- nhist() Histogramm-Grafik mit np.histogram() und plt.bar() (*besser matplotlib.pyplot.hist() nutzen*)
- histstat() statistische Information aus 1d-Histogramm
- nhist2d() 2d-Histogramm mit np.histogram2d, plt.colormesh() (*besser matplotlib.pyplot.hist2d() nutzen*)
- hist2dstat() statistische Information aus 2d-histogramm
- profile2d() “profile plot” für 2d-Streudiagramm
- chi2p\_indep2d()  $\chi^2$ -Test auf Unabhängigkeit zweier Variabler

5. Lineare Regression und Anpassen von Funktionen:

- linRegression() lineare Regression,  $y=ax+b$ , mit analytische Formel
- linRegressionXY() lineare Regression,  $y=ax+b$ , mit x- und y-Unsicherheiten ! veraltet, ``odFit`` mit linearem Model verwenden
- kRegression() lineare Regression,  $y=ax+b$ , mit (korrelierten) x- und y-Unsicherheiten ! veraltet, ``k2Fit`` mit linearem Modell verwenden
- odFit() Funktionsanpassung mit x- und y-Unsicherheiten (scipy ODR)
- mFit() Funktionsanpassung mit (korrelierten) x- und y-Unsicherheiten mit *phyFit*
- kFit() Funktionsanpassung mit (korrelierten) x- und y-Unsicherheiten mit dem Pakte *kafe*, ! veraltet, ``k2Fit`` verwenden
- k2Fit() Funktionsanpassung mit (korrelierten) x- und y-Unsicherheiten mit dem Paket *kafe2*

6. Erzeugung simulierter Daten mit MC-Methode:

- smearData() Addieren von zufälligen Unsicherheiten auf Eingabedaten
- generateXYdata() Erzeugen simulierter Datenpunkte ( $x+\Delta_x$ ,  $y+\Delta_y$ )

Die folgenden **Beispiele** illustrieren die Anwendung:

- *test\_readColumnData.py* ist ein Beispiel zum Einlesen von Spalten aus Textdateien; die zugehörigen *Metadaten* können ebenfalls an das Script übergeben werden und stehen so bei der Auswertung zur Verfügung.

- *test\_readtxt.py* liest Ausgabedateien im allgemeinem *.txt*-Format; ASCII-Sonderzeichen außer dem Spalten-Trenner werden ersetzt, ebenso wie das deutsche Dezimalkomma durch den Dezimalpunkt
- *test\_readPicoScope.py* liest Ausgabedateien von USB-Oszillographen der Marke PicoScope im Format *.csv* oder *.txt*.
- *test\_labxParser.py* liest Ausgabedateien von Leybold CASSY im *.labx*-Format. Die Kopfzeilen und Daten von Messreihen werden als Listen in *python* zur Verfügung gestellt.
- *test\_convolutionFilter.py* liest die Datei *Wellenform.csv* und bestimmt Maxima und fallende Flanken des Signals
- *test\_AutoCorrelation.py* liest die Datei *AudioData.csv* und führt eine Analyse der Autokorrelation zur Frequenzbestimmung durch.
- *test\_Fourier.py* illustriert die Durchführung einer Fourier-Transformation eines periodischen Signals, das in der PicoScope-Ausgabedatei *Wellenform.csv* enthalten ist.
- *test\_propagatedError.py* illustriert die Anwendung von numerisch berechneter Fehlerfortpflanzung und korrekter Rundung von Größen mit Unsicherheit
- *test\_linRegression.py* ist eine einfachere Version mit *python*-Bordmitteln zur Anpassung einer Geraden an Messdaten mit Fehlern in Ordinaten- und Abszissenrichtung. Korrelierte Unsicherheiten werden nicht unterstützt.
- *test\_mFit* dient zur Anpassung einer beliebigen Funktion an Messdaten mit Fehlern in Ordinaten- und Abszissenrichtung und mit allen Messpunkten gemeinsamen (d. h. korrelierten) relativen oder absoluten systematischen Fehlern. Dazu wird das Paket *imunit* verwendet, das den am CERN entwickelten Minimierer *MINUIT* nutzt. Da die Kostenfunktion frei definiert und auch während der Anpassung dynamisch aktualisiert werden kann, ist die Implementierung von Parameter-abhängigen Unsicherheiten möglich. Ferner unterstützt *iminuit* die Erzeugung und Darstellung von Profil-Likelihood-Kurven und Konfidenzkonturen, die so mit *mFit* ebenfalls dargestellt werden können.
- *test\_kFit.py* ist mittlerweile veraltet und dient ebenfalls zur Anpassung einer beliebigen Funktion an Messdaten mit Fehlern in Ordinaten- und Abszissenrichtung und mit allen Messpunkten gemeinsamen (d. h. korrelierten) relativen oder absoluten systematischen Fehlern mit dem Paket *kafe*.
- *test\_k2Fit.py* verwendet die Version *kafe2* zur Anpassung einer Funktion an Messdaten mit unabhängigen oder korrelierten relativen oder absoluten Unsicherheiten in Ordinaten- und Abszissenrichtung.
- *test\_simplek2Fit.py* illustriert die Durchführung einer einfachen linearen Regression mit *kafe2* mit einer minimalen Anzahl eigener Codezeilen.
- *test\_Histogram.py* ist ein Beispiel zur Darstellung und statistischen Auswertung von Häufigkeitsverteilungen (Histogrammen) in ein oder zwei Dimensionen.
- *test\_generateXYata.py* zeigt, wie man mit Hilfe von Zufallszahlen "künstliche Daten" zur Veranschaulichung oder zum Test von Methoden zur Datenauswertung erzeugen kann.
- *toyMC\_Fit.py* führt eine große Anzahl Anpassungen an simulierte Daten durch. Durch Vergleich der wahren Werte mit den aus der Anpassung bestimmten Werten lassen sich Verzerrungen der Parameterschätzungen oder die Form der Verteilung der Chi2-Wahrscheinlichkeit überprüfen, die im Idealfall eine Rechteckverteilung im Intervall  $[0,1]$  sein sollte.

Die folgenden *python*-Skripte sind etwas komplexer und illustrieren typische Anwendungsfälle der Module in *PhyPraKit*:

- *kfitf.py* ist ein Kommandozeilen-Werkzeug, mit dem man komfortabel Anpassungen ausführen kann, bei denen Daten und Fit-Funktion in einer einzigen Datei angegeben werden. Beispiele finden sich in den Dateien mit der Endung *.fit*.

- *Beispiel\_Diodenkennlinie.py* demonstriert die Analyse einer Strom-Spannungskennlinie am Beispiel von (künstlichen) Daten, an die die Shockley-Gleichung angepasst wird. Typisch für solche Messungen über einen weiten Bereich von Stromstärken ist die Änderung des Messbereichs und damit der Anzeigegenauigkeit des verwendeten Messgeräts. Im steil ansteigenden Teil der Strom-Spannungskennlinie ist es außerdem wichtig, auch die Unsicherheit der auf der x-Achse aufgetragenen Spannungsmessungen zu berücksichtigen. Eine weitere Komponente der Unsicherheit ergibt sich aus der Kalibrationsgenauigkeit des Messgeräts, die als relative, korrelierte Unsicherheit aller Messwerte berücksichtigt werden muss. Das Beispiel zeigt, wie man in diesem Fall die Kovarianzmatrix aus Einzelunsicherheiten aufbaut. Die Funktionen *k2Fit()* und *mfit()* bieten dazu komfortable und leicht zu verwendende Interfaces, deren Anwendung zur Umsetzung des komplexen Fehlermodells in diesem Beispiel gezeigt wird.
- *Beispiel\_Drehpendel.py* demonstriert die Analyse von am Drehpendel mit CASSY aufgenommenen Daten. Enthalten sind einfache Funktionen zum Filtern und Bearbeiten der Daten, zur Suche nach Extrema und Anpassung einer Einhüllenden, zur diskreten Fourier-Transformation und zur Interpolation von Messdaten mit kubischen Spline-Funktionen.
- *Beispiel\_Hysteresis.py* demonstriert die Analyse von Daten, die mit einem USB-Oszilloskop der Marke *PicoScope* am Versuch zur Hysteresis aufgenommen wurden. Die aufgezeichneten Werte für Strom und B-Feld werden in einen Zweig für steigenden und fallenden Strom aufgeteilt, mit Hilfe von kubischen Splines interpoliert und dann integriert.
- *Beispiel\_Wellenform.py* zeigt eine typische Auswertung periodischer Daten am Beispiel der akustischen Anregung eines Metallstabs. Genutzt werden Fourier-Transformation und eine Suche nach charakteristischen Extrema. Die Zeitdifferenzen zwischen deren Auftreten im Muster werden bestimmt, als Häufigkeitsverteilung dargestellt und die Verteilungen statistisch ausgewertet.
- *Beispiel\_GammaSpektroskopie.py* liest mit dem Vielkanalanalysator des CASSY-Systems im *.labx*-Format gespeicherten Dateien ein (Beispieldatei *GammaSpektra.labx*).

## MODULE DOCUMENTATION

**PhyPraKit** a collection of tools for data handling, visualisation and analysis in Physics Lab Courses, recommended for “Physikalisches Praktikum am KIT”

PhyPraKit.**A0\_readme**()  
Package PhyPrakit

**PhyPraKit** for Data Handling, Visualisation and Analysis

contains the following functions:

1. Data input:
  - readColumnData() read data and meta-data from text file
  - readCSV() read data in csv-format from file with header
  - readtxt() read data in “txt”-format from file with header
  - readPicoScope() read data from PicoScope
  - readCassy() read CASSY output file in .txt format
  - labxParser() read CASSY output file, .labx format
  - writeCSV() write data in csv-format (opt. with header)
  - writeTexTable() write data in LaTeX table format
  - round\_to\_error() round to same number of significant digits as uncertainty
  - ustring() return rounded value +/- uncertainty as formatted string; alternative: the data type *ufloat(v,u)* of package *uncertainties* comfortably supports printing of values *v* with uncertainties *u*.
2. signal processing:
  - offsetFilter() subtract an offset in array *a*
  - meanFilter() apply sliding average to smoothen data
  - resample() average over *n* samples
  - simplePeakfinder() find peaks and dips in an array, (*recommend to use convolutionPeakfinder*)
  - convolutionPeakfinder() find maxima (peaks) in an array
  - convolutionEdgefinder() find maxima of slope (rising) edges in an array
  - Fourier\_fft() fast Fourier transformation of an array
  - FourierSpectrum() Fourier transformation of an array (*slow, preferably use fft version*)

- autocorrelate() autocorrelation function

3. statistics:

- wmean calculate weighted mean
- BuildCovarianceMatrix build covariance matrix from individual uncertainties
- Cov2Cor convert covariance matrix to correlation matrix
- Cor2Cov convert correlation matrix + errors to covariance matrix
- chi2prob calculate  $\chi^2$  probability
- propagatedError determine propagated uncertainty, with covariance; hint: the data type `ufloat(v,u)` of package `uncertainties` comfortably supports functions of values  $v$  with uncertainties  $u$  with correct error propagation
- getModelError determine uncertainty of parameter-dependent model function

4. histograms tools:

- barstat() statistical information (mean, sigma, error\_on\_mean) from bar chart
- nhist() histogram plot based on `np.histogram()` and `plt.bar()` *better use `matplotlib.pyplot.hist()`*
- histstat() statistical information from 1d-histogram
- nhist2d() 2d-histogram plot based on `np.histogram2d`, `plt.colormesh()` *(better use `matplotlib.pyplot.hist2d`)*
- hist2dstat() statistical information from 2d-histogram
- profile2d() “profile plot” for 2d data
- chi2p\_indep2d()  $\chi^2$  test on independence of data

5. linear regression and function fitting:

- linRegression() linear regression,  $y=ax+b$ , with analytical formula
- linRegressionXY() linear regression,  $y=ax+b$ , with  $x$  and  $y$  errors ! deprecated, use ``odFit`` with linear model instead
- kRegression() linear regression,  $y=ax+b$ , with (correlated) errors on  $x$ , and  $y$  ! deprecated, consider using ``k2Fit`` with linear model instead
- odFit() fit function with  $x$  and  $y$  errors (scipy ODR)
- mFit() fit with with correlated  $x$  and  $y$  errors, profile likelihood and contour lines (module `phyFit`)
- kFit() fit function with (correlated) errors on  $x$  and  $y$  (with package `kafe`, deprecated)
- k2Fit() fit function with (correlated) errors on  $x$  and  $y$  (with package `kafe2`)

6. simulated data with MC-method:

- smearData() add random deviations to input data
- generateXYdata() generate simulated data

`PhyPraKit.BuildCovarianceMatrix` (*sig, sigc=[]*)

Construct a covariance matrix from independent and correlated error components



**Args:**

- sig: iterable of independent errors
- sigc: list of iterables of correlated uncertainties

**Returns:** covariance Matrix as numpy-array

`PhyPraKit.Cor2Cov(sig, C)`

Convert a covariance-matrix into diagonal errors + Correlation matrix

**Args:**

- sig: 1d numpy array of correlated uncertainties
- C: correlation matrix as numpy array

**Returns:**

- V: covariance matrix as numpy array

`PhyPraKit.Cov2Cor(V)`

Convert a covariance-matrix into diagonal errors + Correlation matrix

**Args:**

- V: covariance matrix as numpy array

**Returns:**

- diag uncertainties (sqrt of diagonal elements)
- C: correlation matrix as numpy array

`PhyPraKit.FourierSpectrum(t, a, fmax=None)`

Fourier transform of amplitude spectrum a(t), for equidistant sampling times (a simple implementation for didactical purpose only, consider using `Fourier_fft()`)

**Args:**

- t: np-array of time values
- a: np-array amplitude a(t)

**Returns:**

- arrays freq, amp: frequencies and amplitudes

`PhyPraKit.Fourier_fft(t, a)`

Fourier transform of the amplitude spectrum a(t)

**method:** uses `numpy.fft` and `numpy.fftfreq`; output amplitude is normalised to number of samples;

**Args:**

- t: np-array of time values
- a: np-array amplitude a(t)

**Returns:**

- arrays f, a\_f: frequencies and amplitudes

`PhyPraKit.autocorrelate(a)`

calculate autocorrelation function of input array

method: for array of length  $l$ , calculate  $a[0]=\sum_{i=0}^{l-1} a[i]*[i]$  and  $a[i]= 1/a[0] * \sum_{k=0}^{l-i} a[i] * a[i+k-1]$  for  $i=1, l-1$

**Args:**

- `a`: np-array

**Returns**

- np-array of  $\text{len}(a)$ , the autocorrelation function

`PhyPraKit.barstat(bincont, bincent, pr=True)`

statistics from a bar chart (histogram) with given bin contents and bin centres

**Args:**

- `bincont`: array with bin content
- `bincent`: array with bin centres

**Returns:**

- float: mean, sigma and sigma on mean

`PhyPraKit.chi2p_indep2d(H2d, bcx, bcy, pr=True)`

perform a chi2-test on independence of  $x$  and  $y$

method: chi2-test on compatibility of 2d-distribution,  $f(x,y)$ , with product of marginal distributions,  $f_x(x) * f_y(y)$

**Args:**

- `H2d`: histogram array (as returned by `histogram2d`)
- `bcx`: bin contents  $x$  (marginal distribution  $x$ )
- `bcy`: bin contents  $y$  (marginal distribution  $y$ )

**Returns:**

- float: p-value w.r.t. assumption of independence

`PhyPraKit.chi2prob(chi2, ndf)`

chi2-probability

**Args:**

- `chi2`: chi2 value
- `ndf`: number of degrees of freedom

**Returns:**

- float: chi2 probability

`PhyPraKit.convolutionEdgefinder(a, width=10, th=0.0)`

find positions of maximal positive slope in data

**method:** convolute array  $a$  with an edge template of given width and return extrema of convoluted signal, i.e. places of rising edges

**Args:**

- `a`: array-like, input data
- `width`: int, width of signal to search for

- th: float,  $0 \leq \text{th} \leq 1$ ., relative threshold above (global)minimum

**Returns:**

- pidx: list, indices (in original array) of rising edges

PhyPraKit.**convolutionFilter**(a, v, th=0.0)

convolute normalized array with tmplate funtion and return maxima

**method:** convolute array a with a template and return extrema of convoluted signal, i.e. places where template matches best

**Args:**

- a: array-like, input data
- a: array-like, template
- th: float,  $0 \leq \text{th} \leq 1$ ., relative threshold for places of best match above (global) minimum

**Returns:**

- pidx: list, indices (in original array) of best matches

PhyPraKit.**convolutionPeakfinder**(a, width=10, th=0.0)

**find positions of all Peaks in data** (simple version for didactical purpose, consider using `scipy.signal.find_peaks_cwt()`)

**method:** convolute array a with rectangular template of given width and return extrema of convoluted signal, i.e. places where template matches best

**Args:**

- a: array-like, input data
- width: int, width of signal to search for
- th: float,  $0 \leq \text{th} \leq 1$ ., relative threshold for peaks above (global)minimum

**Returns:**

- pidx: list, indices (in original array) of peaks

PhyPraKit.**generateXYdata**(xdata, model, sx, sy, mpar=None, srelx=None, srely=None, xabscor=None, yabscor=None, xrelcor=None, yrelcor=None)

Generate measurement data according to some model assumes xdata is measured within the given uncertainties; the model function is evaluated at the assumed “true” values xtrue, and a sample of simulated measurements is obtained by adding random deviations according to the uncertainties given as arguments.

**Args:**

- xdata: np-array, x-data (independent data)
- model: function that returns (true) model data (y-dat) for input x
- mpar: list of parameters for model (if any)

**the following are single floats or arrays of length of x**

- sx: gaussian uncertainty(ies) on x
- sy: gaussian uncertainty(ies) on y
- srelx: relative gaussian uncertainty(ies) on x
- srely: relative gaussian uncertainty(ies) on y

**the following are common (correlated) systematic uncertainties**

- xabscor: absolute, correlated error on x
- yabscor: absolute, correlated error on y
- xrelcor: relative, correlated error on x
- yrelcor: relative, correlated error on y

**Returns:**

- np-arrays of floats:
  - xtrue: true x-values
  - ytrue: true value = model(xtrue)
  - ydata: simulated data

PhyPraKit.**getModelError** (*x, model, pvals, pcov*)  
determine uncertainty of model at x from parameter uncertainties

**Formula:**  $\Delta(x) = \sqrt{\sum_{i,j} (df/dp_i(x) df/dp_j(x) V_{p_i,j})}$

**Args:**

- x: scalar or 1d-array of x values
- model: model function
- pvals: parameter values
- covp: covariance matrix of parameters

Returns: \* model uncertainty/ies, same length as x

PhyPraKit.**hist2dstat** (*H2d, xed, yed, pr=True*)  
calculate statistical information from 2d Histogram

**Args:**

- H2d: histogram array (as returned by histogram2d)
- xed: bin edges in x
- yed: bin edges in y

**Returns:**

- float: mean x
- float: mean y
- float: variance x
- float: variance y
- float: covariance of x and y
- float: correlation of x and y

PhyPraKit.**histstat** (*binc, bine, pr=True*)  
calculate mean, standard deviation and uncertainty on mean of a histogram with bin-contents *binc* and bin-edges *bine*

**Args:**

- binc: array with bin content
- bine: array with bin edges

**Returns:**

- float: mean, sigma and sigma on mean

`PhyPraKit.k2Fit` (*func*, *x*, *y*, *sx=None*, *sy=None*, *srelx=None*, *srely=None*, *xabscor=None*, *yabscor=None*, *xrelcor=None*, *yrelcor=None*, *ref\_to\_model=True*, *constraints=None*, *p0=None*, *limits=None*, *plot=True*, *axis\_labels=['x-data', 'y-data']*, *data\_legend='data'*, *model\_expression=None*, *model\_name=None*, *model\_legend='model'*, *model\_band='\$\mu \pm 1 \sigma\$'*, *fit\_info=True*, *plot\_band=True*, *asym\_parerrs=True*, *plot\_cor=False*, *showplots=True*, *quiet=True*)

Fit an arbitrary function `func(x, *par)` to data points (*x*, *y*) with independent and correlated absolute and/or relative errors on *x*- and *y*- values with package `iminuit`.

Correlated absolute and/or relative uncertainties of input data are specified as numpy-arrays of floats; they enter in the diagonal and off-diagonal elements of the covariance matrix. Values of 0. may be specified for data points not affected by a correlated uncertainty. E.g. the array `[0., 0., 0.5., 0.5]` results in a correlated uncertainty of 0.5 of the 3rd and 4th data points. Providing lists of such array permits the construction of arbitrary covariance matrices from independent and correlated uncertainties of (groups of) data points.

**Args:**

- *func*: function to fit
- *x*: np-array, independent data
- *y*: np-array, dependent data

components of uncertainty (optional, use `None` if not relevant)

**single float, array of length of x, or a covariance matrix**

- *sx*: scalar, 1d or 2d np-array, uncertainty(ies) on *x*
- *sy*: scalar, 1d or 2d np-array, uncertainty(ies) on *y*

**single float or array of length of x**

- *srelx*: scalar or 1d np-array, relative uncertainties *x*
- *srely*: scalar or 1d np-array, relative uncertainties *y*

**single float or array of length of x, or a list of such objects,** used to construct a covariance matrix from components

- *xabscor*: scalar or 1d np-array, absolute, correlated error(s) on *x*
- *yabscor*: scalar or 1d np-array, absolute, correlated error(s) on *y*
- *xrelcor*: scalar or 1d np-array, relative, correlated error(s) on *x*
- *yrelcor*: scalar or 1d np-array, relative, correlated error(s) on *y*

**fit options**

- *ref\_to\_model*, bool: refer relative errors to model if true, else use measured data
- *p0*: array-like, initial guess of parameters
- parameter constraints: (name, value, uncertainty)
- *limits*: (nested) list(s) (name, min, max)

**output options**

- *plot*: flag to switch off graphical output
- *axis\_labels*: list of strings, axis labels *x* and *y*

- `data_legend`: legend entry for data points
- `model_name`: latex name for model function
- `model_expression`: latex expression for model function
- `model_legend`: legend entry for model
- `model_band`: legend entry for model uncertainty band
- `fit_info`: controls display of fit results on figure
- `plot_band`: suppress model uncertainty-band if False
- `asym_parerrs`: show (asymmetric) errors from profile-likelihood scan
- `plot_cor`: show profile curves and contour lines
- `showplots`: show plots on screen, default = True
- `quiet`: controls text output

**Returns:**

- np-array of float: parameter values
- np-array of float: parameter errors
- np-array: cor correlation matrix
- float: chi2 chi-square

`PhyPraKit.kFit` (*func*, *x*, *y*, *sx=None*, *sy=None*, *p0=None*, *p0e=None*, *xabscor=None*, *yabscor=None*, *xrelcor=None*, *yrelcor=None*, *constraints=None*, *plot=True*, *title='Daten'*, *axis\_labels=['X', 'Y']*, *fit\_info=True*, *quiet=False*)

fit function *func* with errors on *x* and *y*; uses package *kafe*

!!! deprecated, consider using `k2Fit()` with *kafe2* instead

**Args:**

- *func*: function to fit
- *x*: np-array, independent data
- *y*: np-array, dependent data

**the following are single floats or arrays of length of *x***

- *sx*: scalar or np-array, uncertainty(ies) on *x*
- *sy*: scalar or np-array, uncertainty(ies) on *y*
- *p0*: array-like, initial guess of parameters
- *p0e*: array-like, initial guess of parameter uncertainties
- *xabscor*: absolute, correlated error(s) on *x*
- *yabscor*: absolute, correlated error(s) on *y*
- *xrelcor*: relative, correlated error(s) on *x*
- *yrelcor*: relative, correlated error(s) on *y*
- *parameter constrains* (name, value, uncertainty)
- *title*: string, title of graph
- *axis\_labels*: List of strings, axis labels *x* and *y*

- parameter constraints: (name, value, uncertainty)
- plot: flag to switch off graphical output
- title: name of data set
- axis labels: labels for x and y axis
- fit info: controls display of fit results on figure
- quiet: flag to suppress text and log output

**Returns:**

- np-array of float: parameter values
- np-array of float: parameter errors
- np-array: cor correlation matrix
- float: chi2 chi-square

PhyPraKit.**kRegression**(x, y, sx, sy, xabscor=None, yabscor=None, xrelcor=None, yrelcor=None, title='Daten', axis\_labels=['x', 'y-data'], plot=True, quiet=False)

linear regression  $y(x) = ax + b$  with errors on x and y; uses package *kafe*

!!! deprecated, consider using k2Fit() with linear model

**Args:**

- x: np-array, independent data
- y: np-array, dependent data

**the following are single floats or arrays of length of x**

- sx: scalar or np-array, uncertainty(ies) on x
- sy: scalar or np-array, uncertainty(ies) on y
- xabscor: absolute, correlated error(s) on x
- yabscor: absolute, correlated error(s) on y
- xrelcor: relative, correlated error(s) on x
- yrelcor: relative, correlated error(s) on y
- title: string, title of graph
- axis\_labels: List of strings, axis labels x and y
- plot: flag to switch off graphical output
- quiet: flag to suppress text and log output

**Returns:**

- float: a slope
- float: b constant
- float: sa sigma on slope
- float: sb sigma on constant
- float: cor correlation
- float: chi2 chi-square

`PhyPraKit.labxParser` (*file*, *prlevel=1*)  
read files in xml-format produced with Leybold CASSY

**Args:**

- *file*: input data in .labx format
- *prlevel*: control printout level, 0=no printout

**Returns:**

- list of strings: tags of measurement vectors
- 2d list: measurement vectors read from file

`PhyPraKit.linRegression` (*x*, *y*, *sy=None*)  
linear regression  $y(x) = ax + b$

**method:** analytical formula

**Args:**

- *x*: np-array, independent data
- *y*: np-array, dependent data
- *sy*: scalar or np-array, uncertainty on *y*

**Returns:**

- float: *a* slope
- float: *b* constant
- float: *sa* sigma on slope
- float: *sb* sigma on constant
- float: *cor* correlation
- float: *chi2* chi-square

`PhyPraKit.linRegressionXY` (*x*, *y*, *sx=None*, *sy=None*)  
linear regression  $y(x) = ax + b$  with errors on *x* and *y* uses numerical “orthogonal distance regression” from package `scipy.odr`

!!! deprecated, consider using `odFit()` with linear model instead

**Args:**

- *x*: np-array, independent data
- *y*: np-array, dependent data
- *sx*: scalar or np-array, uncertainty(ies) on *x*
- *sy*: scalar or np-array, uncertainty(ies) on *y*

**Returns:**

- float: *a* slope
- float: *b* constant
- float: *sa* sigma on slope
- float: *sb* sigma on constant
- float: *cor* correlation



- float: chi2 chi-square

PhyPraKit **.mFit** (*fitf*, x, y, *sx=None*, *sy=None*, *srelx=None*, *srely=None*, *xabscor=None*, *xrelcor=None*, *yabscor=None*, *yrelcor=None*, *ref\_to\_model=True*, *p0=None*, *constraints=None*, *limits=None*, *use\_negLogL=True*, *plot=True*, *plot\_cor=False*, *plot\_band=True*, *showplots=True*, *quiet=False*, *axis\_labels=['x', 'y = f(x, \*par)']*, *data\_legend='data'*, *model\_legend='model'*)

Fit an arbitrary function *fitf*(x, \*par) to data points (x, y) with independent and correlated absolute and/or relative errors on x- and y- values with class *mnFit* from package *phyFit* (uses *iminuit*).

Correlated absolute and/or relative uncertainties of input data are specified as numpy-arrays of floats; they enter in the diagonal and off-diagonal elements of the covariance matrix. Values of 0. may be specified for data points not affected by a correlated uncertainty. E.g. the array [0., 0., 0.5., 0.5] results in a correlated uncertainty of 0.5 of the 3rd and 4th data points. Providing lists of such arrays permits the construction of arbitrary covariance matrices from independent and correlated uncertainties of (groups of) data points.

#### Args:

- *fitf*: model function to fit, arguments (float:x, float: \*args)
- x: np-array, independent data
- y: np-array, dependent data
- *sx*: scalar or 1d or 2d np-array , uncertainties on x data
- *sy*: scalar or 1d or 2d np-array , uncertainties on x data
- *srelx*: scalar or np-array, relative uncertainties x
- *srely*: scalar or np-array, relative uncertainties y
- *yabscor*: scalar or np-array, absolute, correlated error(s) on y
- *yrelcor*: scalar or np-array, relative, correlated error(s) on y
- *p0*: array-like, initial guess of parameters
- *use\_negLogL*: use full  $-2\ln(L)$
- *constraints*: (nested) list(s) [name or id, value, error]
- *limits*: (nested) list(s) [name or id, min, max]
- *plot*: show data and model if True
- *plot\_cor*: show profile likelihoods and confidence contours
- *plot\_band*: plot uncertainty band around model function
- *showplots*: show plots on screen, default = False
- *quiet*: suppress printout
- *list of str*: axis labels
- *str*: legend for data
- *str*: legend for model

#### Returns:

- np-array of float: parameter values
- 2d np-array of float: parameter uncertainties [0]: neg. and [1]: pos.
- np-array: correlation matrix
- float: chi2 chi-square of fit a minimum

PhyPraKit.**meanFilter** (*a*, *width=5*)

apply a sliding average to smoothen data,

**method:** value at index *i* and  $\text{int}(\text{width}/2)$  neighbours are averaged to form the new value at index *i*

**Args:**

- *a*: np-array of values
- *width*: int, number of points to average over (if *width* is an even number, *width*+1 is used)

**Returns:**

- *av* smoothed signal curve

PhyPraKit.**nhist** (*data*, *bins=50*, *xlabel='x'*, *ylabel='frequency'*)

Histogram.hist show a one-dimensional histogram

**Args:**

- *data*: array containing float values to be histogrammed
- *bins*: number of bins
- *xlabel*: label for x-axis
- *ylabel*: label for y axis

**Returns:**

- float arrays: bin contents and bin edges

PhyPraKit.**nhist2d** (*x*, *y*, *bins=10*, *xlabel='x axis'*, *ylabel='y axis'*, *clabel='counts'*)

Histogram.hist2d create and plot a 2-dimensional histogram

**Args:**

- *x*: array containing x values to be histogrammed
- *y*: array containing y values to be histogrammed
- *bins*: number of bins
- *xlabel*: label for x-axis
- *ylabel*: label for y axis
- *clabel*: label for colour index

**Returns:**

- float array: array with counts per bin
- float array: histogram edges in x
- float array: histogram edges in y

PhyPraKit.**odFit** (*fitf*, *x*, *y*, *sx=None*, *sy=None*, *p0=None*)

fit an arbitrary function with errors on x and y uses numerical “orthogonal distance regression” from package `scipy.odr`

**Args:**

- *fitf*: function to fit, arguments (array:P, float:x)
- *x*: np-array, independent data
- *y*: np-array, dependent data

- `sx`: scalar or np-array, uncertainty(ies) on x
- `sy`: scalar or np-array, uncertainty(ies) on y
- `p0`: array-like, initial guess of parameters

**Returns:**

- np-array of float: parameter values
- np-array of float: parameter errors
- np-array: cor correlation matrix
- float: chi2 chi-square

`PhyPraKit.offsetFilter(a)`

correct an offset in array a (assuming a symmetric signal around zero) by subtracting the mean

`PhyPraKit.profile2d(H2d, xed, yed)`

**generate a profile plot from 2d histogram:**

- mean y at a centre of x-bins, standard deviations as error bars

**Args:**

- `H2d`: histogram array (as returned by `histogram2d`)
- `xed`: bin edges in x
- `yed`: bin edges in y

**Returns:**

- float: array of bin centres in x
- float: array mean
- float: array rms
- float: array sigma on mean

`PhyPraKit.propagatedError(function, pvals, pcov)`

determine propagated uncertainty (with covariance matrix)

Formula:  $\Delta = \sqrt{\sum_{i,j} (df/dp_i df/dp_j V_{p_i,j})}$

**Args:**

- `function`: function of parameters `pvals`, a 1-d array is also allowed, eg. `function(*p) = f(x, *p)`
- `pvals`: parameter values
- `pcov`: covariance matrix (or uncertainties) of parameters

**Returns:**

- uncertainty  $\Delta$ ( `function(*par)` )

`PhyPraKit.readCSV(file, nlhead=1, delim=',')`

read Data in .csv format, skip header lines

**Args:**

- `file`: string, file name
- `nlhead`: number of header lines to skip

- `delim`: column separator

**Returns:**

- `hlines`: list of string, header lines
- `data`: 2d array, 1st index for columns

`PhyPraKit.readCassy` (*file*, *prlevel=0*)

read Data exported from Cassy in .txt format

**Args:**

- `file`: string, file name
- `prlevel`: printout level, 0 means silent

**Returns:**

- `units`: list of strings, channel units
- `data`: tuple of arrays, channel data

`PhyPraKit.readColumnData` (*fname*, *cchar='#*', *delimiter=None*, *pr=True*)

**read column-data from file**

- input is assumed to be columns of floats
- characters following `<cchar>`, and `<cchar>` itself, are ignored
- words with preceeding '\*' are taken as keywords for meta-data, text following the keyword is returned in a dictionary

**Args:**

- string `fnam`: file name
- int `ncols`: number of columns
- char `delimiter`: character separating columns
- bool `pr`: print input to std out if True

`PhyPraKit.readPicoScope` (*file*, *prlevel=0*)

read Data exported from PicoScope in .txt or .csv format

**Args:**

- `file`: string, file name
- `prlevel`: printout level, 0 means silent

**Returns:**

- `units`: list of strings, channel units
- `data`: tuple of arrays, channel data

`PhyPraKit.readtxt` (*file*, *nlhead=1*, *delim='\n'*)

**read floating point data in general txt format** skip header lines, replace decimal comma, remove special characters

**Args:**

- `file`: string, file name
- `nhead`: number of header lines to skip

- `delim`: column separator

**Returns:**

- `hlines`: list of string, header lines
- `data`: 2d array, 1st index for columns

`PhyPraKit.resample(a, t=None, n=11)`

perform average over `n` data points of array `a`, return reduced array, eventually with corresponding time values

**method:** value at index `i` and `int(width/2)` neighbours are averaged to form the new value at index `i`

**Args:**

- `a`, `t`: np-arrays of values of same length
- `width`: int, number of values of array `a` to average over (if `width` is an even number, `width+1` is used)

**Returns:**

- `av`: array with reduced number of samples
- `tav`: a second, related array with reduced number of samples

`PhyPraKit.round_to_error(val, err, nsd_e=2)`

round float `val` to corresponding number of significant digits as uncertainty `err`

**Arguments:**

- `val`, float: value
- `err`, float: uncertainty of value
- `nsd_e`, int: number of significant digits of `err`

**Returns:**

- int: number of significant digits for `v`
- float: `val` rounded to precision of `err`
- float: `err` rounded to precision `nsd_e`

`PhyPraKit.simplePeakfinder(x, a, th=0.0)`

**find positions of all maxima (peaks) in data** x-coordinates are determined from weighted average over 3 data points

**this only works for very smooth data with well defined extrema** use `convolutionPeakfinder` or `scipy.signal.argrelemax()` instead

**Args:**

- `x`: np-array of positions
- `a`: np-array of values at positions `x`
- `th`: float, threshold for peaks

**Returns:**

- np-array: x positions of peaks as weighted mean over neighbours
- np-array: y values corresponding to peaks

`PhyPraKit.smearData(d, s, srel=None, absco=None, relco=None)`

Generate measurement data from “true” input by adding random deviations according to the uncertainties

**Args:**

- d: np-array, (true) input data

**the following are single floats or arrays of length of array d**

- s: gaussian uncertainty(ies) (absolute)
- srel: gaussian uncertainties (relative)

**the following are common (correlated) systematic uncertainties**

- absco: 1d np-array of floats or list of np-arrays: absolute correlated uncertainties
- relco: 1d np-array of floats or list of np-arrays: relative correlated uncertainties

**Returns:**

- np-array of floats: dm, smeared (=measured) data

`PhyPraKit.ustring(v, e, pe=2)`

**v +/- e as formatted string** with number of significant digits corresponding to precision pe of uncertainty

**Args:**

- v: value
- e: uncertainty
- pe: precision (=number of significant digits) of uncertainty

**Returns:**

- string: <v> +/- <e> with appropriate number of digits

`PhyPraKit.wmean(x, sx, V=None, pr=True)`

**weighted mean of np-array x with uncertainties sx** or covariance matrix V; if both are given,  $sx^{**2}$  is added to the diagonal elements of the covariance matrix

**Args:**

- x: np-array of values
- sx: np-array uncertainties
- V: optional, covariance matrix of x
- pr: if True, print result

**Returns:**

- float: mean, sigma

`PhyPraKit.writeCSV(file, ldata, hlines=[], fmt='%10g', delim=',', nline='\n', **kwargs)`  
write data in .csv format, including header lines

**Args:**

- file: string, file name
- ldata: list of columns to be written
- hlines: list with header lines (optional)
- fmt: format string (optional)
- delim: delimiter to separate values (default comma)
- nline: newline string

**Returns:**

- 0/1 for success/fail

PhyPraKit.**writeTextTable** (*file*, *ldata*, *cnames*=[], *caption*="", *fmt*='%*10g*')  
write data formatted as latex tabular

**Args:**

- file: string, file name
- ldata: list of columns to be written
- cnames: list of column names (optional)
- caption: LaTeX table caption (optional)
- fmt: format string (optional)

**Returns:**

- 0/1 for success/fail

package phyFit.py

Physics Fitting with *iminuit* [<https://iminuit.readthedocs.io/en/stable/>]

Author: Guenter Quast, initial version Jan. 2021

**Requirements:**

- Python  $\geq 3.6$
- supports iminuit vers.  $< 2$  and  $\geq 2$ .
- scipy  $> 1.5.0$
- matplotlib  $> 3$

The class *mnFit.py* uses the package *iminuit* for fitting a parameter-dependent model  $f(x, *par)$  to data points  $(x, y)$  with independent and/or correlated absolute and/or relative uncertainties in the  $x$  and/or  $y$  directions. An example function *mFit()* illustrates how to control the interface of *mnFit*, and a short script is provided to perform a fit on sample data.

**Method:** A user-defined cost function in *iminuit* with uncertainties that depend on model parameters is dynamically updated during the fitting process. Data points with relative errors can thus be referred to the model instead of the data. The derivative of the model function w.r.t.  $x$  is used to project the covariance matrix of  $x$ -uncertainties on the  $y$ -axis.

The implementation in this example is minimalistic and intended to illustrate the principle of an advanced usage of *iminuit*. It is also meant to stimulate own studies with special, user-defined cost functions.

**The main features of this package are:**

- definition of a custom cost function
- implementation of the least squares method with correlated errors
- support for correlated  $x$ -uncertainties by projection on the  $y$ -axis
- support of relative errors with reference to the model values
- evaluation of profile likelihoods to determine asymmetric uncertainties
- plotting of profile likelihood and confidence contours

The **cost function** that is optimized is a least-squares one, or an extended version if parameter-dependent uncertainties are present. In the latter case, the logarithm of the determinant of the covariance matrix is added to the least-squares cost function, so that it corresponds to twice the negative log-likelihood of a multivariate Gaussian distribution.

A fully functional example is provided by the function `mFit()` and the executable script below, which contains sample data, executes the fitting procedure and collects the results.

```
PhyPraKit.phyFit.mFit (fitf, x, y, sx=None, sy=None, srelx=None, srely=None, xabscor=None,
                      xrelcor=None, yabscor=None, yrelcor=None, ref_to_model=True,
                      p0=None, constraints=None, limits=None, use_negLogL=True,
                      plot=True, plot_cor=True, showplots=True, plot_band=True,
                      quiet=False, axis_labels=['x', 'y = f(x, *par)'], data_legend='data',
                      model_legend='model')
```

Fit an arbitrary function `fitf(x, *par)` to data points `(x, y)` with independent and/or correlated absolute and/or relative errors on `x`- and/or `y`- values with class `mnFit` using the package `iminuit`.

Correlated absolute and/or relative uncertainties of input data are specified as floats (if all uncertainties are equal) or as numpy-arrays of floats. The concept of independent or common uncertainties of (groups) of data points is used to construct the full covariance matrix from different uncertainty components. Independent uncertainties enter only in the diagonal, while correlated ones contribute to diagonal and off-diagonal elements of the covariance matrix. Values of 0. may be specified for data points not affected by a certain type of uncertainty. E.g. the array `[0., 0., 0.5., 0.5]` specifies uncertainties only affecting the 3rd and 4th data points. Providing lists of such arrays permits the construction of arbitrary covariance matrices from independent and correlated uncertainties of (groups of) data points.

#### Args:

- `fitf`: model function to fit, arguments (float:x, float: \*args)
- `x`: np-array, independent data
- `y`: np-array, dependent data
- `sx`: scalar or 1d or 2d np-array, uncertainties on x data
- `sy`: scalar or 1d or 2d np-array, uncertainties on y data
- `srelx`: scalar or np-array, relative uncertainties x
- `srely`: scalar or np-array, relative uncertainties y
- `yabscor`: scalar or np-array, absolute, correlated error(s) on y
- `yrelcor`: scalar or np-array, relative, correlated error(s) on y
- `p0`: array-like, initial guess of parameters
- `use_negLogL`: use full  $-2\ln(L)$
- `constraints`: (nested) list(s) [name or id, value, error]
- `limits`: (nested) list(s) [name or id, min, max]
- `plot`: show data and model if True
- `plot_cor`: show profile likelihoods and confidence contours
- `plot_band`: plot uncertainty band around model function
- `quiet`: suppress printout
- `list of str`: axis labels
- `str`: legend for data



- str: legend for model

**Returns:**

- np-array of float: parameter values
- 2d np-array of float: parameter uncertainties [0]: neg. and [1]: pos.
- np-array: correlation matrix
- float: chi2 chi-square of fit a minimum

**class** PhyPraKit.phyFit.mnFit

**Fit an arbitrary function  $f(x, *par)$  to data** with independent and/or correlated absolute and/or relative uncertainties

This implementation depends on and heavily uses features of the minimizer **iminuit**.

Public methods:

- `init_data()`: initialize data and uncertainties
- `init_fit()`: initialize fit: data, model and parameter constraints
- `setOptions()`: set options for mnFit
- `do_fit()`: perform fit
- `plotModel()`: plot model function and data
- `plotContours()`: plot profile likelihoods and confidence contours
- `getResult()`: access to final fit results
- `getFunctionError()`: uncertainty of model at point(s)  $x$  for parameters  $p$
- `plot_Profile()`: plot profile Likelihood for parameter
- `plot_clContour()`: plot confidence level contour for pair of parameters
- `plot_nsigContour()`: plot n-sigma contours for pair of parameters

Public data members:

- `ParameterNames`: names of parameters (as specified in model function)
- `Chi2`: chi2 at best-fit point
- `NDoF`: number of degrees of freedom
- `ParameterValues`: parameter values at best-fit point
- `MigradErrors`: symmetric uncertainties
- `CovarianceMatrix`: covariance matrix
- `CorrelationMatrix`: correlation matrix
- `OneSigInterval`: one-sigma (68% CL) ranges of parameter values
- `covx`: covariance matrix of x-data
- `covy`: covariance matrix of y-data
- `cov`: combined covariance matrix, including projected x-uncertainties

Instances of sub-classes:

- `minuit.*`: methods and members of Minuit object
- `data.*`: methods and members of sub-class DataUncertainties

- `costf.*`: methods and members of sub-class `xLSQ`

**static** `CL2Chi2 (CL)`

calculate DeltaChi2 from confidence level CL

**static** `Chi22CL (dc2)`

calculate confidence level CL from DeltaChi2

**class** `DataUncertainties (outer, x, y, ex, ey, erelx, erely, cabsx, crelx, cabsy, crely, quiet=True)`

Handle data and uncertainties, build covariance matrices from components

**Args:**

- `outer`: pointer to instance of calling object
- `x`: abscissa of data points ("x values")
- `y`: ordinate of data points ("y values")
- `ex`: independent uncertainties x
- `ey`: independent uncertainties y
- `erelx`: independent relative uncertainties x
- `erely`: independent relative uncertainties y
- `cabsx`: correlated absolute uncertainties x
- `crelx`: correlated relative uncertainties x
- `cabsy`: correlated absolute uncertainties y
- `crely`: correlated relative uncertainties y
- `quiet`: no informative printout if True

**Public methods:**

- `get_Cov()`: final covariance matrix (incl. proj. x)
- `get_xCov()`: covariance of x-values
- `get_yCov()`: covariance of y-values
- `get_iCov()`: inverse covariance matrix

**Data members:**

- copy of all input arguments
- `covx`: covariance matrix of x
- `covy`: covariance matrix of y uncertainties
- `cov`: full covariance matrix incl. projected x
- `iCov`: inverse of covariance matrix

**get\_Cov ()**

return covariance matrix of data

**get\_iCov ()**

return inverse of covariance matrix, as used in cost function

**get\_xCov ()**

return covariance matrix of x-data

---

**get\_yCov()**  
return covariance matrix of y-data

**static chi2prb(chi2, ndof)**  
Calculate chi2-probability from chi2 and degrees of freedom

**do\_fit()**  
perform all necessary steps of fitting sequence

**static getFunctionError(x, model, pvals, covp)**  
determine error of model at x  
Formula:  $\Delta(x) = \sqrt{\sum_{i,j} (df/dp_i(x) df/dp_j(x) V_{p_i,j})}$

**Args:**

- x: scalar or np-array of x values
- model: model function
- pvals: parameter values
- covp: covariance matrix of parameters

**Returns:**

- model uncertainty, same length as x

**getResult()**  
return most important results as numpy arrays

**static get\_functionSignature(f)**  
get arguments and keyword arguments passed to a function

**init\_data(x, y, ex=None, ey=1.0, erelx=None, erely=None, cabsx=None, crelx=None, cabsy=None, crely=None)**  
initialize data object

**Args:**

- x: abscissa of data points ("x values")
- y: ordinate of data points ("y values")
- ex: independent uncertainties x
- ey: independent uncertainties y
- erelx: independent relative uncertainties x
- erely: independent relative uncertainties y
- cabsx: correlated absolute uncertainties x
- crelx: correlated relative uncertainties x
- cabsy: correlated absolute uncertainties y
- crely: correlated relative uncertainties y
- quiet: no informative printout if True

**init\_fit(model, p0=None, constraints=None, limits=None)**  
initialize fit object

**Args:**

- model: model function f(x; \*par)

---

- `p0`: np-array of floats, initial parameter values
- `constraints`: (nested) list(s): [parameter name, value, uncertainty] or [parameter index, value, uncertainty]
- `limits`: (nested) list(s): [parameter name, min, max] or [parameter index, min, max]

**plotContours** ()

Plot grid of profile curves and one- and two-sigma contour lines from `iminuit` object

**Arg:**

- `iminuitObject`

**Returns:**

- matplotlib figure

**plotModel** (*axis\_labels*=['x', 'y = f(x, \*par)'], *data\_legend*='data', *model\_legend*='fit',  
*plot\_band*=True)

Plot model function and data

Uses `iminuitObject` abd cost Fuction of type `LSQwithCov`

**Args:**

- list of str: axis labels
- str: legend for data
- str: legend for model

**Returns:**

- matplotlib figure

**plot\_Profile** (*pnam*)

plot profile likelihood of parameter `pnam`

**plot\_clContour** (*pnam1*, *pnam2*, *cl*)

plot a contour of parameters `pnam1` and `pnam2` with confidence level(s) `cl`

**plot\_nsigContour** (*pnam1*, *pnam2*, *nsig*)

plot `nsig` contours of parameters `pnam1` and `pnam2`

**static round\_to\_error** (*val*, *err*, *nsd\_e*=2)

round float `val` to same number of sigfinicant digits as uncertainty `err`

**Returns:**

- int: number of significant digits for `v`
- float: `val` rounded to precision of `err`
- float: `err` rounded to precision `nsd_e`

**setLimits** (*limits*)

store parameter limits

format: nested list(s) of type [parameter name, min, max] or [parameter index, min, max]

**setOptions** (*relative\_refers\_to\_model*=None, *run\_minos*=None, *use\_negLogL*=None, *quiet*=None)

Define `mnFit` options

**Args:**

- rel. errors refer to model else data
- run minos else don\*t run minos

- use full neg2logL
- don't provide printout else verbose printout

**class xLSQ** (*outer, data, model, use\_neg2logL=False, quiet=True*)

Custom e\_x\_tended Least-SQuares cost function with dynamically updated covariance matrix and -2log(L) correction term for parameter-dependent uncertainties

For data points (x, y) with model f(x, \*p) and covariance matrix V(f(x,\*p)) the cost function is:

$$-2 \ln \mathcal{L} = \chi^2(y, V^{-1}, f(x, *p)) + \ln(\det(V(f(x, *p))))$$

For uncertainties depending on the model parameters, a more efficient approach is used to calculate the likelihood, which uses the Cholesky decomposition of the covariance matrix into a product of a triangular matrix and its transposed

$$V = LL^T,$$

thus avoiding the costly calculation of the inverse matrix.

$$\chi^2 = r \cdot (V^{-1}r) \text{ with } r = y - f(x, *p)$$

is obtained by solving the linear equation

$$VX = r, \text{ i.e. } X = V^{-1}r \text{ and } \chi^2 = r \cdot X$$

with the effecient linear-equation solver *scipy.linalg.cho\_solve(L,x)* for Cholesky-decomposed matrices.

The determinant is efficiently calculated by taking the product of the diagonal elements of the matrix L,

$$\det(V) = 2 \prod L_{i,i}$$

Input:

- outer: pointer to instance of calling class
- data: data object of type DataUncertainties
- model: model function f(x, \*par)
- use\_neg2logL: use full -2log(L) instead of chi2 if True

`__call__` method of this class is called by `iminuit`

Data members:

- ndof: degrees of freedom
- nconstraints: number of parameter constraints
- chi2: chi2-value (goodness of fit)
- use\_neg2logL: usage of full 2\*neg Log Likelihood
- quiet: no printpout if True

Methods:

- model(x, \*par)

**setConstraints** (*constraints*)

Add parameter constraints

format: nested list(s) of type [parameter name, value, uncertainty] or [parameter index, value, uncertainty]

**test\_readColumnData.py** test data input from text file with module `PhyPraKit.readColumnData`

**test\_readtxt.py** uses `readtxt()` to read floating-point column-data in very general .txt formats, here the output from PicoTech 8 channel data logger, with ' ' separated values, 2 header lines, german decimal comma and special character '^@'

**test\_readPicoSocpe.py** read data exported by PicoScope usb-oscilloscope

**test\_labxParser.py** read files in xml-format produced with the Leybold Cassy system uses `PhyPraKit.labxParser()`

**test\_Histogram.py** demonstrate histogram functionality in `PhyPraKit`

**test\_convolutionFilter.py** Read data exported with PicoScope usb-oscilloscope, here the accoustic excitation of a steel rod

Demonstrates usage of `convolutionFilter` for detection of signal maxima and falling edges

**test\_AutoCorrelation.py** test function `autocorrelate()` in `PhyPraKit`; determines the frequency of a periodic signal from maxima and minima of the autocorrelation function and performs statistical analysis of time between peaks/dips

uses `readCSV()`, `autocorrelate()`, `convolutionPeakfinder()` and `histstat()` from `PhyPraKit`

**test\_Fourier.py** Read data exported with PicoScope usb-oscilloscope, here the accoustic excitation of a steel rod

Demonstraion of a Fourier transformation of the signal

**test\_propagatedError.py** Beispiel: Numerische Fehlerfortpflanzung mit `PhyPraKit.prpagatedError()` Illustriert auch die Verwendung der Rundung auf die Genauigkeit der Unsicherheit.

**test\_kRegression** test linear regression with kafe using `kFit` from `PhyPrakKit` uncertainties in x and y and correlated absolute and relative uncertainties

**test\_odFit** test fitting an arbitrary fucntion with `scipy odr`, with uncertainties in x and y

**test\_mFit.py** Fitting example with `iminiut`

Uses function `PhyPraKit.mFit`, which in turn uses `mnFit` from `phyFit`

This is a rather complete example showing a fit to data with independent and correlated, absolute and relative uncertainties in the x and y directions.

**test\_kFit** test fitting an arbitrary function with kafe, with uncertainties in x and y and correlated absolute and relative uncertainties

**test\_k2Fit** Illustrate fitting of an arbitrary function with kafe2 This example illustrates the special features of kafe2: - correlated errors for x and y data - relative errors with reference to model - profile likelihood method to evaluate asymmetric errors - plotting of profile likelihood and confidence contours

**test\_generateData** test generation of simulated data this simulates a measurement with given x-values with uncertainties; random deviations are then added to arrive at the true values, from which the true y-values are then calculated according to a model function. In the last step, these true y-values are smeared by adding random deviations to obtain a sample of measured values

**toyMC\_Fit.py** run a large number of fits on toyMC data to check for biases and chi2-probability distribution

This rather complete example uses eight different kinds of uncertainties, namely independent and correlated, absolute and relative ones in the x and y directions.

**kfitf.py** Perform a fit with the kafe package driven by input file

usage: kfitf.py [-h] [-n] [-s] [-c] [--noinfo] [-f FORMAT] filename

**positional arguments:** filename name of fit input file

**optional arguments:**

<b>-h, --help</b>	show this help message and exit
<b>-n, --noplots</b>	suppress output of plots on screen
<b>-s, --saveplot</b>	save plot(s) in file(s)
<b>-c, --contour</b>	plot contours and profiles
<b>--noinfo</b>	suppress fit info on plot
<b>--noband</b>	suppress 1-sigma band around function
<b>--format FMT</b>	graphics output format, default FMT = pdf

**Beispiel\_Diodenkennlinie.py** Messung einer Strom-Spannungskennlinie und Anpassung der Shockley-Gleichung.

- Konstruktion der Kovarianzmatrix für reale Messinstrumente mit Signalrauschen, Anzeigeunsicherheiten und korrelierten, realtiven Kalibrationsunsicherheiten für die Strom- und Spannungsmessung.
- Ausführen der Anpassung der Shockley-Gleichung mit *k2Fit* oder *mFit* aus dem Paket *PhyPraKit*. Wichtig: die Modellfunktion ist nicht nach oben beschränkt, sondern divergiert sehr schnell. Daher muss der verwendete numerische Optimierer Parameterlimits unterstützen.

**Beispiel\_Drehpendel.py** Auswertung der Daten aus einer im CASSY labx-Format gespeicherten Datei am Beispiel des Drehpendels

- Einlesen der Daten im .labx-Format
- Säubern der Daten durch verschiedene Filterfunktionen: - offset-Korrektur - Glättung durch gleitenden Mittelwert - Zusammenfassung benachbarter Daten durch Mittelung
- Fourier-Transformation (einfach und fft)
- Suche nach Extrema (*peaks* und *dips*)
- Anpassung von Funktionen an Einhüllende der Maxima und Minima
- Interpolation durch Spline-Funktionen
- numerische Ableitung und Ableitung der Splines
- Phasenraum-Darstellung (aufgezeichnete Wellenfunktion gegen deren Ableitung nach der Zeit)

**Beispiel\_Hysteresep.py** Auswertung der Daten aus einer mit PicoScope erstellten Datei im txt-Format am Beispiel des Hystereseversuchs

- Einlesen der Daten aus PicoScope-Datei vom Typ .txt oder .csv
- Darstellung Kanal\_a vs. Kanal\_b
- Auftrennung in zwei Zweige für steigenden bzw. abnehmenden Strom
- Interpolation durch kubische Splines
- Integration der Spline-Funktionen

**Beispiel\_Wellenform.py** Einlesen von Daten aus dem mit PicoScope erstellten Dateien am Beispiel der akustischen Anregung eines Stabes

- Fourier-Analyse des Signals

- Bestimmung der Resonanzfrequenz mittels Autokorrelation

**Beispiel\_GammaSpektroskopie.py** Darstellung der Daten aus einer im CASSY labx-Format gespeicherten Datei am Beispiel der Gamma-Spektroskopie

- Einlesen der Daten im .labx-Format



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