QExpy: A python package for undergraduate laboratories

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Outline

- Motivation
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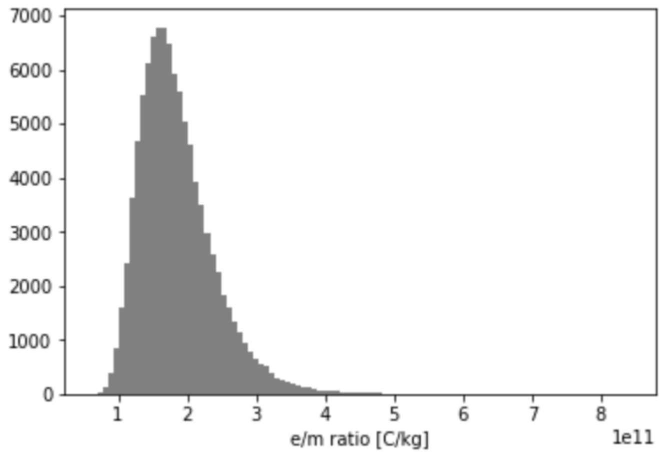
- Plotting in QExpy
- Using QExpy

Motivation 1: Is it that useful for students to "manually" propagate errors?

- What do we want students learning in the lab, in terms of data analysis?
  - Is it useful for them to get very good at error propagation and taking partial derivatives?
  - Do you propagate errors "à la" undergrad in your own research?
- We had a lot of complaints about students "not enjoying" the labs, as they find it very time consuming to work on lab reports and analyse data out of the lab

→ **Let's take the tedious error propagation out of the labs and have the students think about the physics and the data instead!**

```
From error propagation:
e/m = (1.75 +/- 0.48) 10^11 C/kg
From Monte Carlo, using the mean and standard deviation
e/m = (1.85 +/- 0.54) 10^11 C/kg
```




```
Using Monte Carlo method with mode and 68% confidence:
e/m = (1.55 +/- 0.55) 10^11 C/kg with 71.74% confidence
```

Motivation 2: Have a “professor approved” computing package for error propagation

- We teach an error analysis and statistics course to 2nd year students in which we encourage them to use computers for calculations and teach them some python programming.
- After the first year teaching it, one of the students had developed a few python function for propagating errors which he shared with others.
- Decided to hire that student over a summer to develop a more polished and “professor approved” version as a python package.

→ **QExpy: an open source python package that anyone can install**

Error propagation in QExpy

- Designed to be easy to use and compatible with Jupyter Notebooks.
- Define variables of type "**Measurement**"
- Work with those variables, **errors are propagated automatically**.
- Can use **most functions** (e.g. trig, sqrt).
- **Significant figures** can be handled easily.
- **Units** handled somewhat (still in dev).
- Can interface with everything else that you can do in python, e.g. read files of data, etc.

In [3]:

```
import qexpy as q
#Define two measurements, x and y
x = q.Measurement(5,1) #5 +/- 1
y = q.Measurement(10,0.2) # 10 +/- 0.2
#A quantity that depends on these
z = (x+y)/(x-y)
#Choose sig figs to show:
q.set_sigfigs(2)
print("z = ",z)
```

```
z =  -3.00 +/- 0.80
```

Error propagation: implementation

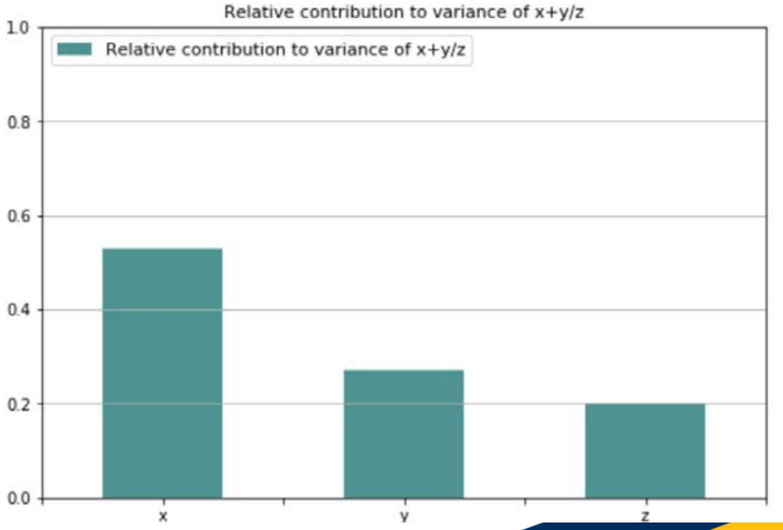
- By default, errors are propagated using the "**derivative method**" (first order, exact derivatives):

$$\sigma_F^2 = \left(\frac{\partial F}{\partial x}\sigma_x\right)^2 + \left(\frac{\partial F}{\partial y}\sigma_y\right)^2 + 2\frac{\partial F}{\partial x}\frac{\partial F}{\partial y}\sigma_{xy}$$

In the statistics class, they learn about this formula, its **limitations**, covariance, etc.

- QExpy also implements "**Min-Max**" and **Monte-Carlo** errors; second year students are using MC error analysis by the end of the year!
- **Arrays** of measurements (mean and std, error-weighted mean), numpy "under the hood"
- **Visualize error contributions** (still in dev)

```
import qexpy as q
x = q.Measurement(5,0.1,name='x')
y = q.Measurement(6,0.5,name='y')
z = q.Measurement(7,0.5,name='z')
u = (x+y/z)
u.show_error_contribution()
```



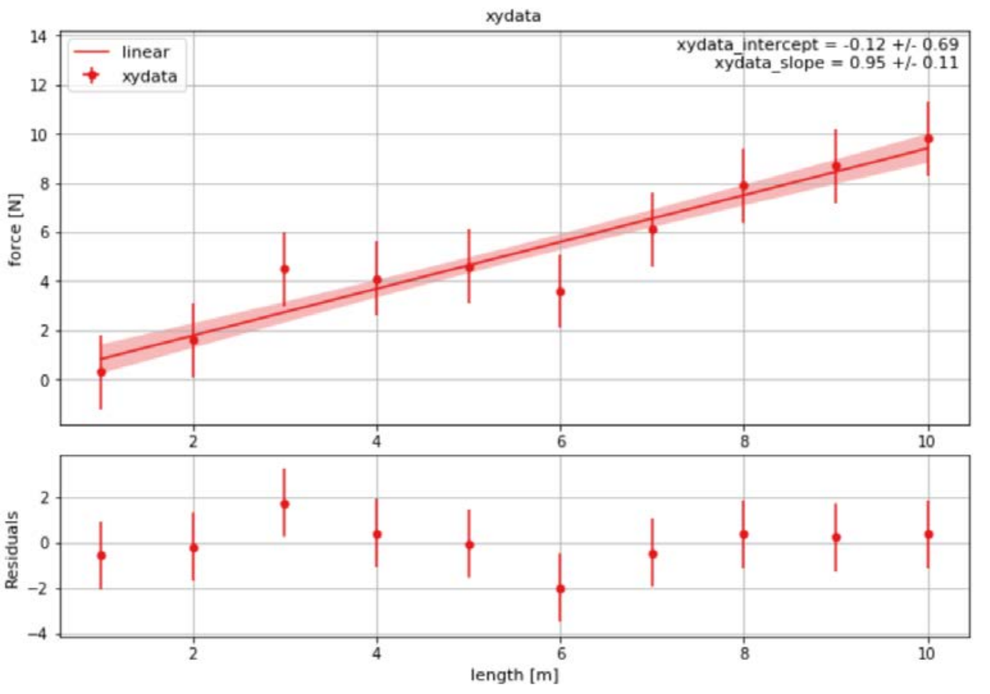
Plotting and fitting made easy

In [11]:
```
#Define a plot object
fig1 = q.MakePlot(xdata = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10],
                  ydata = [0.3, 1.6, 4.5, 4.1, 4.6, 3.6, 6.1, 7.9, 8.7, 9.8],
                  yerr = 1.5,
                  xname = 'length', xunits='m',
                  yname = 'force', yunits='N',
                  data_name = 'xydata')
#Fit to a linear function
results = fig1.fit("linear")
#Add residuals sub plot
fig1.add_residuals()
fig1.show()
```

```
-----------------Fit results------------------
Fit of  xydata  to  linear
Fit parameters:
xydata_linear_fit0_fitpars_intercept = -0.12 +/- 0.69,
xydata_linear_fit0_fitpars_slope = 0.95 +/- 0.11

Correlation matrix:
[[ 1.     -0.886]
 [-0.886  1.   ]]

chi2/ndof = 3.62/7
---------------End fit results---------------
```

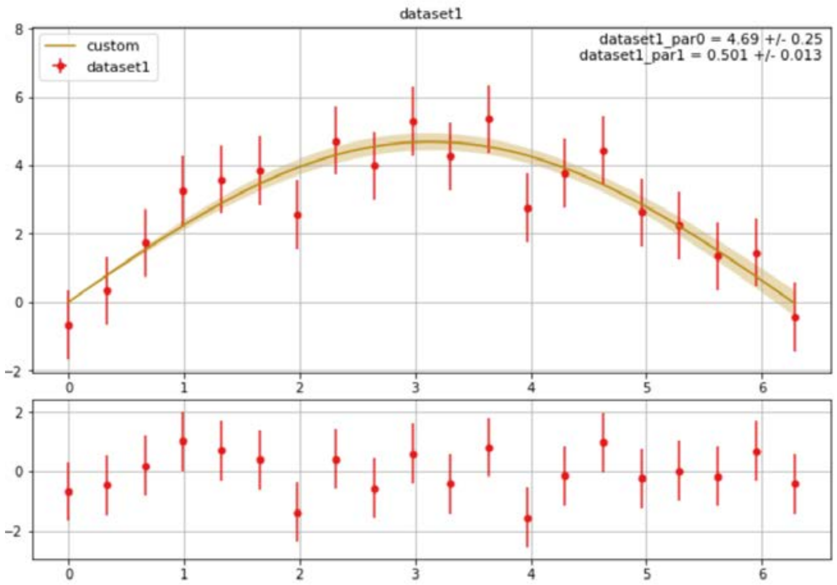


Plotting and fitting

- Plotting through **Bokeh** (interactive) or **matplotlib**, can access backend and fine tune the look of the plots, defaults are reasonable in most cases.
- Fitting for **polynomials and Gaussian** included, users can also provide their own **custom functions.**
- **Error bands** are correct (MC errors that include correlations between parameters) → can use to plot any function where there are errors and correlations between parameters and it will draw the error bands!

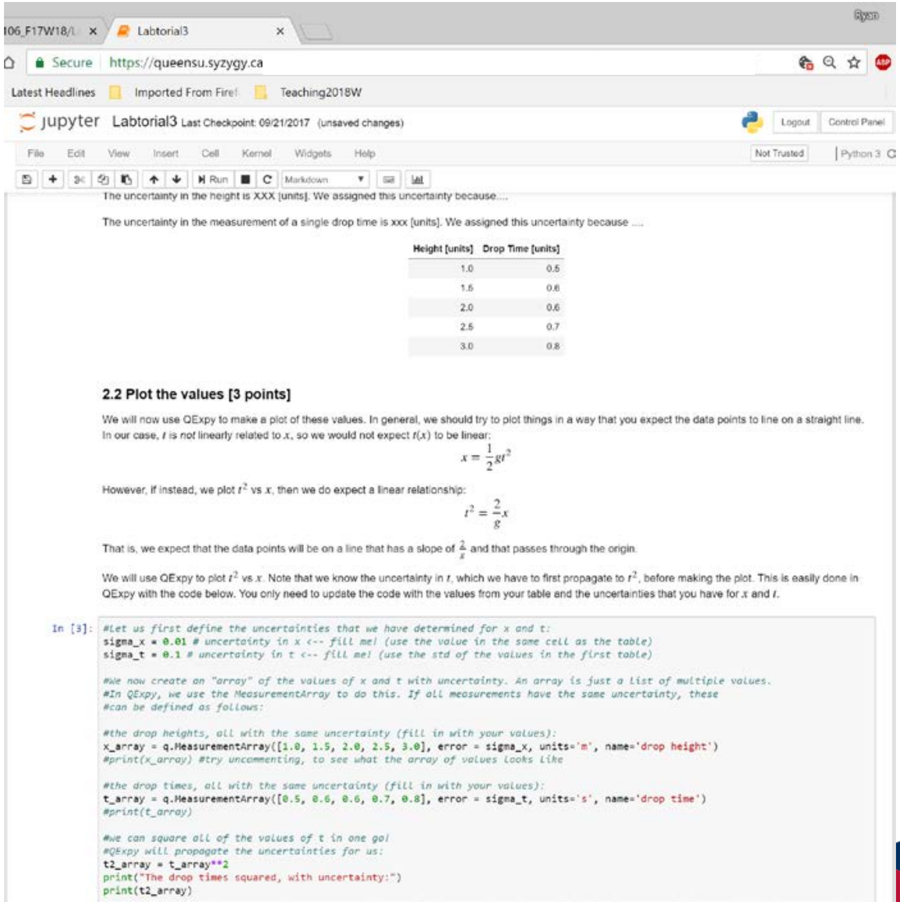
```
#define our model with 2 parameters:
def model (x, *pars):
    return pars[0]*np.sin(pars[1]*x)

#fit the model - we must provide a guess for the parameters
fig4.fit(model, parguess=[1,1], fitcolor="darkgoldenrod")
fig4.add_residuals()
fig4.show()
```



Use of QExpy at Queen’s

- Students using it in all years, engineering and A&S, through **Jupyter Notebooks.**
- In the error analysis and statistics class, students are not allowed to use QExpy; they are instead encouraged to use python to program their own error analysis routines.
- In the labs, they can use QExpy, since they should, in principle, understand what it is doing behind the scenes.
- Have used in our **first year** calculus-based physics course, as part of a way to introduce students to programming early on. Reasonably successful (this coming year, more python programming intro!).



Me too!

- Install (requires python3):

  pip install qexpy

- Documentation (*Google: qexpy read the docs*):

  http://qexpy.readthedocs.io/en/latest/intro.html

- Examples (*Google: qexpy github*):

  https://github.com/Queens-Physics/qexpy/tree/master/examples/jupyter

- Contribute? (*yes, please!*)

  https://github.com/Queens-Physics/qexpy

Summary

- QExpy is an open source python package for data analysis in undergraduate physics labs (error propagation and plotting).
- QExpy was primarily developed by and for physics students.
- It is helping our students to think more about the physics and the data instead of being bogged down in error propagation.
- Serving as an intro to programming in python to our first year students.
- We have a supporting statistics course to ensure that students have a foundation in data analysis.

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