

# **QExpy: A python package for undergraduate laboratories**

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# Outline



- Motivation
- Error propagation in QExpy
- 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

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

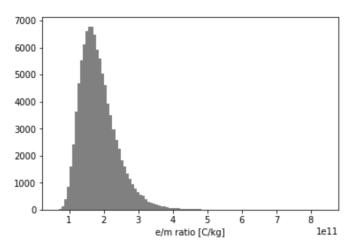


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From error propagation:

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

3

# Motivation 2: Have a "professor approved" computing package for error propagation

- We teach an error analysis and statistics course to 2<sup>nd</sup> 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



**GitHub** 

# **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**

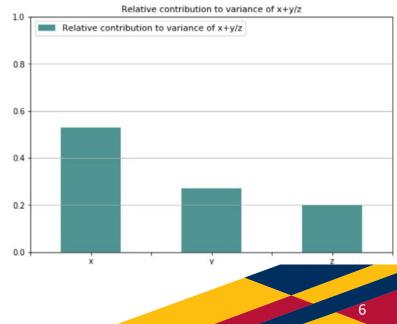
 By default, errors are propagated using the "derivative method" (first order, exact derivatives):

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

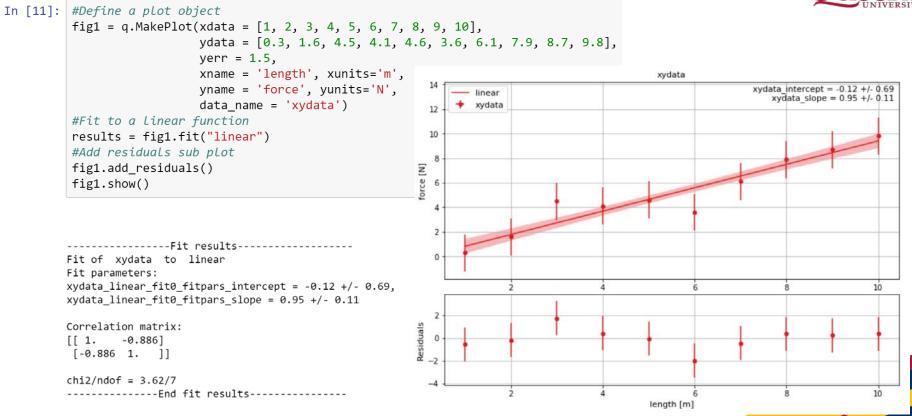
In the statistics class, they learn about this formula, its **limitations**, covariance, etc.

- 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, errorweighted 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



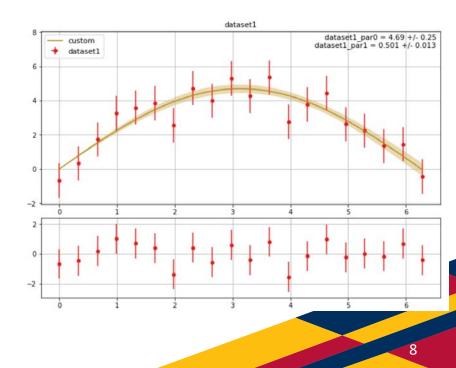


# **Plotting and fitting**

- 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!



#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!).

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- 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











- 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.

#### Acknowledgements:

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- **A.B. McLean** for the original inspiration and valuable discussions
- Undergraduates: **Connor Kapahi, Turner Garrow** for their great work developing the package!

