Exploration of Squeezed Spin States in Python

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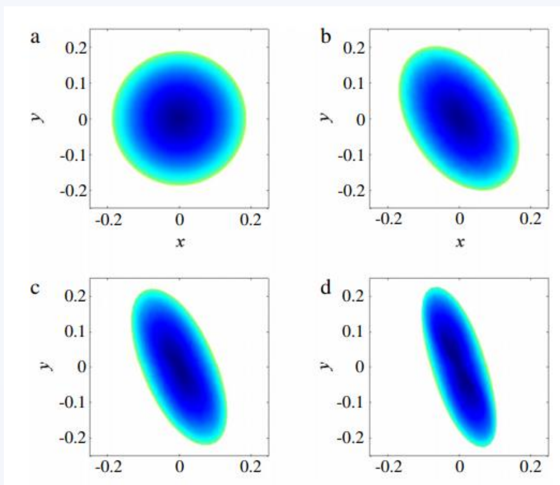
SCAN ME

GitHub

INTRODUCTION

- An exploration of visualizing unsqueezed and squeezed spin states in python and comparing them.
- The image below encapsulates the process of squeezing a spin state [1]. The two axes in the graphs below show the values of the spin projection of a spin state.
- The graph represents the range of measurement results for the projection spins



- Motivation: squeezed states can help develop better measurement methods through reducing measurement uncertainty

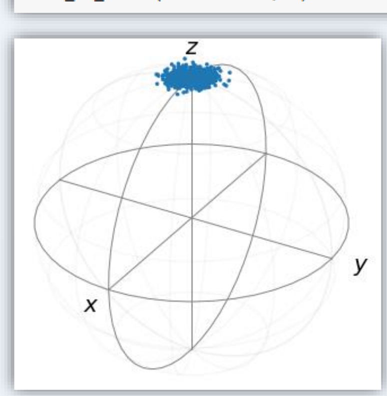
OBJECTIVES

- Explore the visualization of spin state realizations and rotations on a Bloch sphere in Python
- Utilize One Axis Twisting (OAT) and Two Axis Twisting (TAT) to produce squeezed spin states [2]
- Measure and visualize the utility of squeezed spin states relative to unsqueezed spin states
- Goal: to produce a squeezed spin state with the thinnest center; essentially stretching the spin state as much as possible to achieve a narrower distribution

METHODS

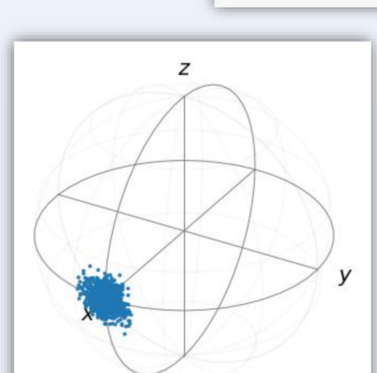
Visualizing an Unsqueezed Spin State

```
#Realization of spin up function on Bloch Sphere
N = 200 #number of atoms
allSresults = [all_S(spinup(N)) for i in range(1000)] #1000 is number of realizations for the set of 200 atoms
show_on_bloch(allSresults, N) #visualization of spin up realization
```



- Establishment of spin up state
- Foundation for all more complex spin states

```
#Rotation along the Y Axis
N = 200
allSresults = [all_S(spinup(N)) for i in range(1000)]
allSresults_X = [single_spin_rotation_along_y(i, -np.pi/2) for i in allSresults]
show_on_bloch(allSresults_X, N)
```



- Rotation along Y Axis
- Easier visualization of the circular shape when rotated
- Easier comparison to squeezed spin state along this axis

METHODS

Visualizing a Squeezed Spin State

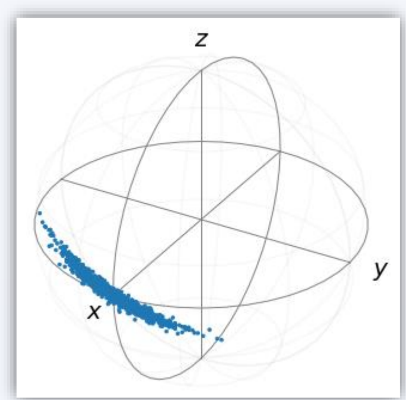
➢ **Writing Evolution Functions**

```
def sz2_evolution(spin_ensemble, t):
  B = all_S(spin_ensemble)[2]
  amount = B * t
  spin_ensemble = [single_spin_rotation_along_z(atom, amount) for atom in spin_ensemble]
  return spin_ensemble
```

Realization of spin ensemble after evolving under Hamiltonian for t

➢ **One Axis Twisting (OAT)**

```
#OAT using sz2_evolution
N = 200
t = 5 / N

final_results = []
all_realizations = []
for realization_index in range(1000):
  spin_ensemble = spinup(N) #establishing initial state of spin_ensemble
  spin_ensemble = [single_spin_rotation_along_y(atom, -np.pi/2) for atom in spin_ensemble] #preparinig spin_ensemble along x-direction
  spin_ensemble = sz2_evolution(spin_ensemble, t) #application of sz2_evolution on the spin_ensemble
  final_results.append(all_S(spin_ensemble)) #calculate all_S (total projection of spin_ensemble)
  all_realizations.append(spin_ensemble) #repeat this process 1000 times by storing all results in a new array

show_on_bloch(final_results, N)
```

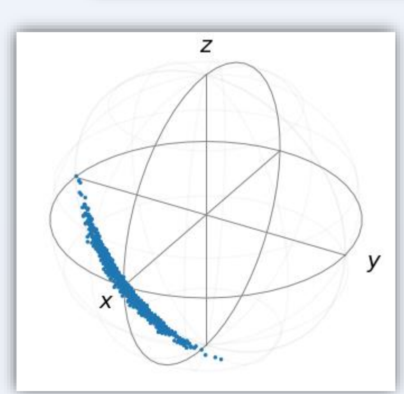


- Sz_2 evolution of spin state
- Other variations with less utility developed in code

➢ **Two Axis Twisting (TAT)**

```
#Defining the perameters of the function TAT_Delta_t(...)
def TAT_Delta_t(spin_ensemble, Delta_t):
  ...
N = 200
t = 5 / N
P = 10
Delta_t = t / (2 * P)
```

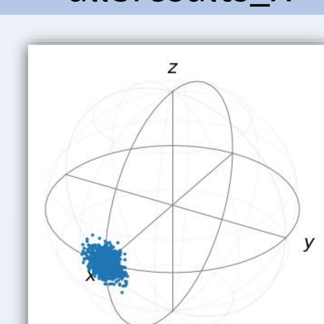
```
# This block is meant to test the funciton TAT_Delta_t(...)
final_results = []
for realization_index in range(1000):
  spin_ensemble = spinup(N)
  spin_ensemble = [single_spin_rotation_along_y(atom, -np.pi/2) for atom in spin_ensemble]
  for _ in range(P):
    spin_ensemble = sz2_evolution(spin_ensemble, Delta_t)
    spin_ensemble = sy2_evolution(spin_ensemble, -Delta_t)
  final_results.append(all_S(spin_ensemble))

show_on_bloch(final_results, N)
```



- Use of two evolution functions
- Twisting along two axes
- Results in spin state rotated 45°

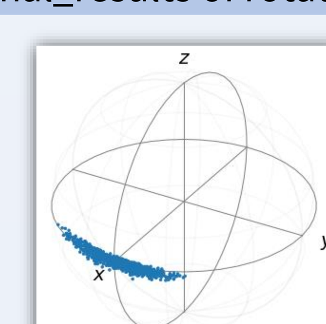
➢ **Setting up Comparison**

allSresults_X



Standard unsqueezed spin state

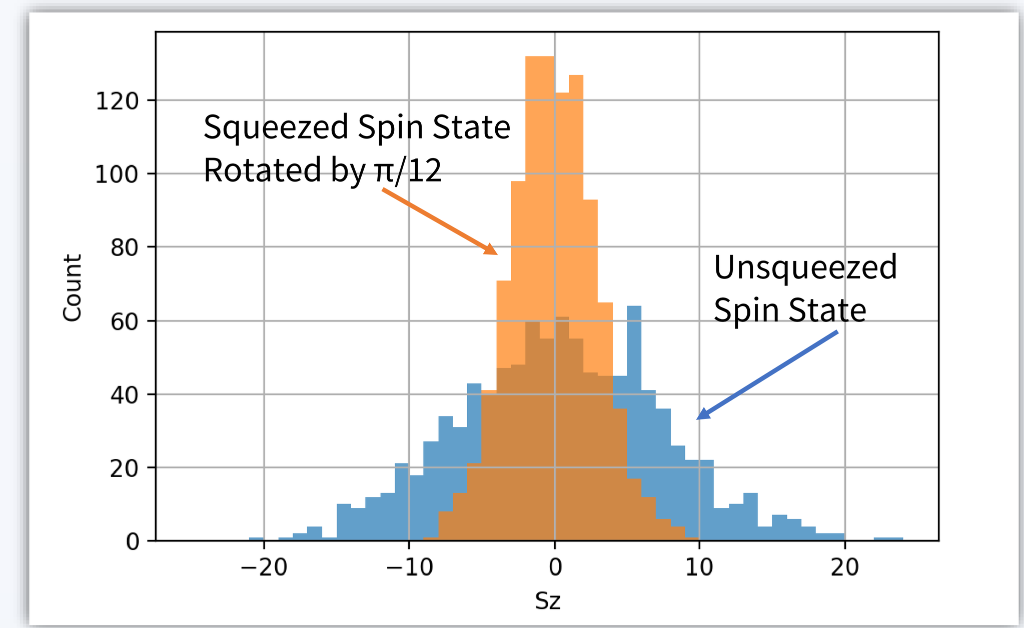
Final_results of rotated OAT



Rotated by π/12 to produce most narrow spin state

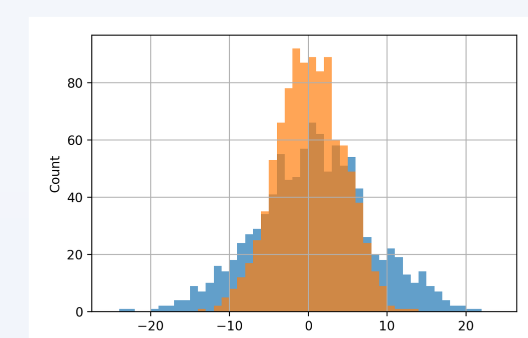
RESULTS

Results of comparison of squeezed vs. unsqueezed state

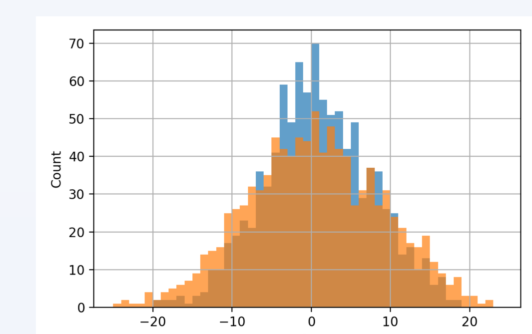


Demonstration of a narrower distribution

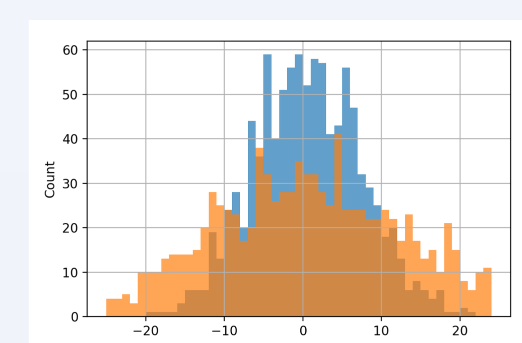
Angle of Rotation Matters



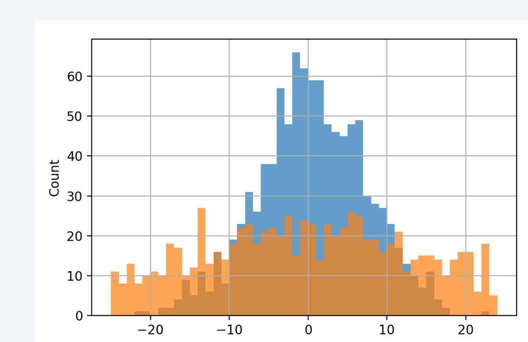
Θ = π /6



Θ = π /4

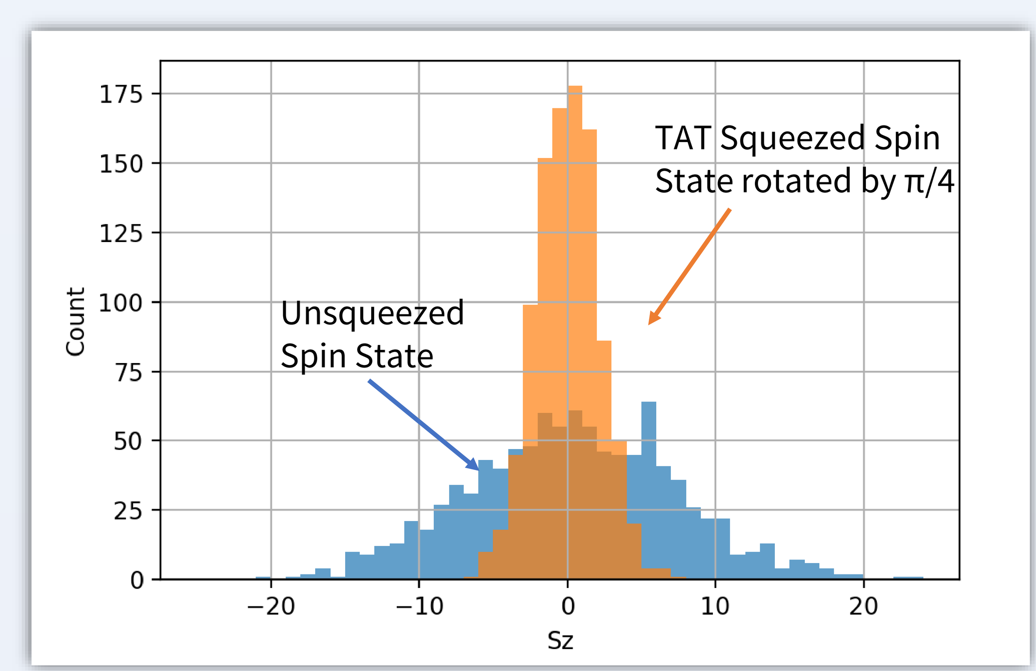


Θ = π /3



Θ = π /2

Testing the TAT Result



Squeezed Spin States produced from TAT result in a narrower distribution

CONCLUSION

- Squeezing spin states can facilitate increased accuracy in measurements as depicted through the narrower distribution seen in the results section
- Not every squeezed spin state will be useful in creating narrower distributions; in the demonstrations done, OAT spin states rotated by a larger theta were the least useful
- Two Axis Twisting (TAT) was shown to be most useful in producing narrower distributions

OUTLOOK

- Can be used as a method to detect quantum entanglement
- Exploring more variations of TAT and comparing their utility to OAT in producing useful squeezed spin states
- Utility of Python in modeling quantum systems, in this case squeezed spin states, facilitating further discussions based on more understandable material

ACKNOWLEDGEMENTS

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REFERENCES

[1] Ma et al., “Quantum Spin Squeezing”, *Phys. Rep.* **509**, 89 (2011)

[2] Kitagawa, Masahiro, and Masahito Ueda. "Squeezed spin states." *Phys. Rev. A* **47**, 5138 (1993)