

# degeneracyCount

December 11, 2025

```
[65]: import numpy as np
import matplotlib.pyplot as plt
import tqdm
```

```
[66]: import sys, pathlib
sys.path.insert(0, str(pathlib.Path.cwd().parent))
```

```
[67]: from decoding.beliefPropagation import performBeliefPropagationFast
from decoding.OSD import performOSD
```

```
[68]: codes = [
    "[72, 12, 6]",
    "[90, 8, 10]",
    "[108, 8, 10]",
    "[144, 12, 12]",
    "[288, 12, 18]",
]

trials = 100
physicalErrorRates = np.logspace(-3.2, -1.3, 8)
results_BP = {}
```

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[69]: np.random.seed(0)
```

```
[70]: for code in tqdm.tqdm(codes):
    oc = np.load(f'../codes/{code}.npz')
    name = code
    results_BP[name] = {}
    code = oc['Hx']
    Lx = oc['Lx']
    distance = oc['distance']
    n = len(code[0])
    logicalErrorRates = []
    BPs_fault_rates = []
    BPs_miscorrected_rates = []
    incorrectable_rates = []
    degeneracies = []
```

```

for errorRate in physicalErrorRates:

    initialBeliefs = [np.log((1 - errorRate) / errorRate)] * n
    logical_error = 0
    BPs_fault = 0
    BPs_miscorrected = 0
    incorruptable = 0
    degenerateErrors = 0

    for _ in range(trials):

        ##### CODE CAPACITY ERROR MODEL #####
        # non-trivial pythonic way to generate random bitstring with given
        ↪ error rate
        error = (np.random.random(n) < errorRate).astype(int)

        syndrome = (error @ code.T) % 2

        ##### SIMPLE PHENOMENOLOGICAL ERROR MODEL #####
        # measurementError = (np.random.random(len(syndrome)) < errorRate).
        ↪ astype(int)
        # syndrome = (syndrome + measurementError) % 2

        detection, isSyndromeFound, llrs =
        ↪ performBeliefPropagationFast(code, syndrome, initialBeliefs, verbose=False)

        if not isSyndromeFound:
            logical_error += 1
            BPs_fault += 1

            # detection = performOSD(code, syndrome, llrs, detection)

        # This is the XOR, between the actual error and the detected error.
        ↪ We are simulating the correction of the error
        residual = (detection + error) % 2

        syndromeLogic = (Lx @ residual) % 2

        if isSyndromeFound and not np.any(syndromeLogic) and (np.
        ↪ array_equal(detection, error) == False):
            degenerateErrors += 1

        if np.any(syndromeLogic):
            logical_error += 1

```

```

        error_weight = np.sum(error)
        if error_weight < (distance // 2):
            BPs_miscorrected += 1
        else:
            incorrectable += 1

    ler = logical_error / trials
    logicalErrorRates.append(ler)
    BPs_fault_rates.append(BPs_fault)
    BPs_miscorrected_rates.append(BPs_miscorrected)
    incorrectable_rates.append(incorrectable)
    degeneracies.append(degenerateErrors)

results_BP[name]['ler'] = logicalErrorRates
results_BP[name]['BPs_fault'] = BPs_fault_rates
results_BP[name]['BPs_miscorrected'] = BPs_miscorrected_rates
results_BP[name]['incorrectable'] = incorrectable_rates
results_BP[name]['degeneracies'] = degeneracies

```

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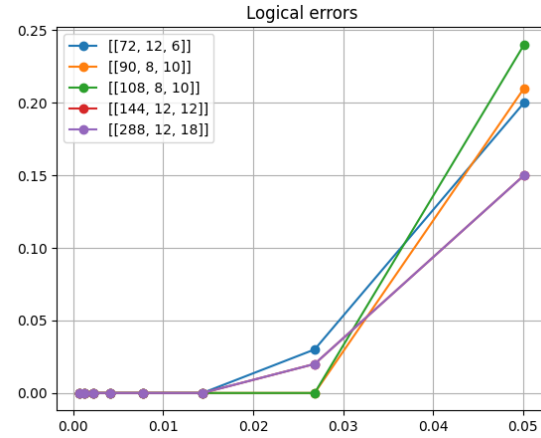
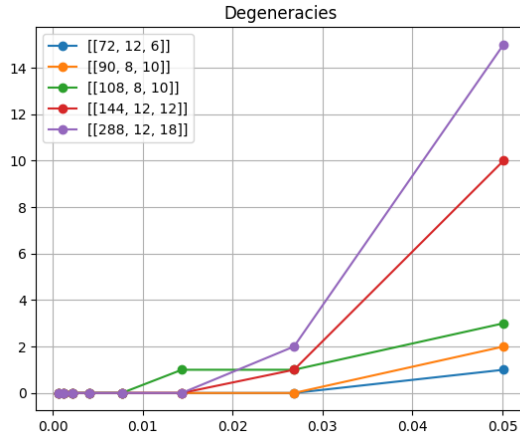
```

[71]: fig, axes = plt.subplots(1, 2, figsize=(14, 5))

for name in results_BP:
    axes[0].plot(physicalErrorRates, results_BP[name]['degeneracies'],
    ↪label=name, marker='o')
    axes[0].grid(True)
    axes[0].legend()
    axes[0].set_title('Degeneracies')

for name in results_BP:
    axes[1].plot(physicalErrorRates, results_BP[name]['ler'], label=name,
    ↪marker='o')
    axes[1].grid(True)
    axes[1].legend()
    axes[1].set_title('Logical errors')

```



```
[72]: names = codes # preserve the original order used to build `results`
code_labels = ['72', '90', '108', '144', '288'] # n values for labeling
x = np.arange(len(physicalErrorRates))
n_codes = len(names)
bar_width = 0.12 # narrower bars
group_spacing = 0.15 # space between groups
```

```
[73]: plt.figure(figsize=(14, 6))
for i, name in enumerate(names):
    bps_fault = np.array(results_BP[name]['BPs_fault'])
    bps_misc = np.array(results_BP[name]['BPs_miscorrected'])
    incorrect = np.array(results_BP[name]['incorrectable'])
    positions = x + i * (bar_width + 0.02) # add small gap between bars

    if i == 0:
        plt.bar(positions, bps_fault, bar_width, label='BPs_fault', color='tab:blue')
        plt.bar(positions, bps_misc, bar_width, bottom=bps_fault, label='BPs_miscorrected', color='tab:orange')
        plt.bar(positions, incorrect, bar_width, bottom=bps_fault + bps_misc, label='incorrectable', color='tab:green')
    else:
        plt.bar(positions, bps_fault, bar_width, color='tab:blue')
        plt.bar(positions, bps_misc, bar_width, bottom=bps_fault, color='tab:orange')
        plt.bar(positions, incorrect, bar_width, bottom=bps_fault + bps_misc, color='tab:green')

# Add code labels (n values) on top of each bar group
for i, name in enumerate(names):
    bps_fault = np.array(results_BP[name]['BPs_fault'])
```

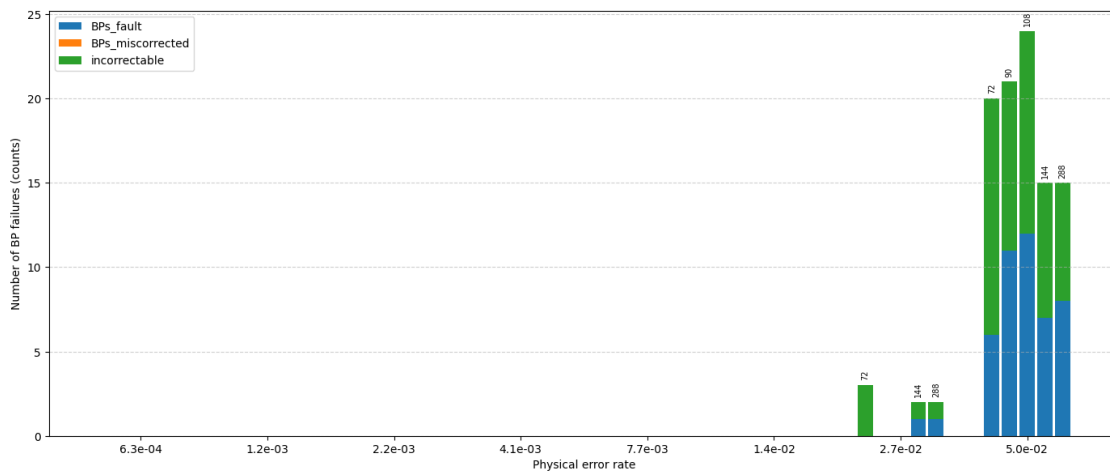
```

bps_misc = np.array(results_BP[name]['BPs_miscorrected'])
incorrect = np.array(results_BP[name]['incorrectable'])
total_height = bps_fault + bps_misc + incorrect
positions = x + i * (bar_width + 0.02)

for j, (pos, height) in enumerate(zip(positions, total_height)):
    if height > 0: # only label bars with data
        plt.text(pos, height + 0.3, code_labels[i], ha='center',
        va='bottom', fontsize=7, rotation=90)

# center x-ticks under each group and format ticks
plt.xticks(x + (n_codes - 1) * (bar_width + 0.02) / 2, [f'{r:.1e}' for r in
physicalErrorRates])
plt.xlabel('Physical error rate')
plt.ylabel('Number of BP failures (counts)')
plt.grid(True, axis='y', linestyle='--', alpha=0.6)
plt.legend(loc='upper left')
plt.tight_layout()
plt.show()

```



```

[74]: results_OSD = {}

for code in tqdm.tqdm(codes):
    oc = np.load(f'../codes/{code}.npz')
    name = code
    results_OSD[name] = {}
    code = oc['Hx']
    Lx = oc['Lx']
    distance = oc['distance']
    n = len(code[0])

```

```

logicalErrorRates = []
BPs_fault_rates = []
BPs_miscorrected_rates = []
incorrectable_rates = []
degeneracies = []

for errorRate in physicalErrorRates:

    initialBeliefs = [np.log((1 - errorRate) / errorRate)] * n
    logical_error = 0
    BPs_fault = 0
    BPs_miscorrected = 0
    incorrectable = 0
    degenerateErrors = 0

    for _ in range(trials):

        ##### CODE CAPACITY ERROR MODEL #####
        # non-trivial pythonic way to generate random bitstring with given
        ↪ error rate
        error = (np.random.random(n) < errorRate).astype(int)

        syndrome = (error @ code.T) % 2

        ##### SIMPLE PHENOMENOLOGICAL ERROR MODEL #####
        # measurementError = (np.random.random(len(syndrome)) < errorRate).
        ↪ astype(int)
        # syndrome = (syndrome + measurementError) % 2

        detection, isSyndromeFound, llrs =
        ↪ performBeliefPropagationFast(code, syndrome, initialBeliefs, verbose=False)

        if not isSyndromeFound:
            # logical_error += 1
            # BPs_fault += 1

            detection = performOSD(code, syndrome, llrs, detection)

        # This is the XOR, between the actual error and the detected error.
        ↪ We are simulating the correction of the error
        residual = (detection + error) % 2

        syndromeLogic = (Lx @ residual) % 2

```

```

osd_syndrome_check = (detection @ code.T) % 2
is_valid_osd = np.array_equal(osd_syndrome_check, syndrome)

if is_valid_osd and not np.any(syndromeLogic) and (np.
↪array_equal(detection, error) == False):
    degenerateErrors += 1

if np.any(syndromeLogic):
    logical_error += 1

    error_weight = np.sum(error)
    if error_weight < (distance // 2):
        BPs_miscorrected += 1
    else:
        incorrectable += 1

ler = logical_error / trials
logicalErrorRates.append(ler)
BPs_fault_rates.append(BPs_fault)
BPs_miscorrected_rates.append(BPs_miscorrected)
incorrectable_rates.append(incorrectable)
degeneracies.append(degenerateErrors)

results_OSD[name]['ler'] = logicalErrorRates
results_OSD[name]['BPs_fault'] = BPs_fault_rates
results_OSD[name]['BPs_miscorrected'] = BPs_miscorrected_rates
results_OSD[name]['incorrectable'] = incorrectable_rates
results_OSD[name]['degeneracies'] = degeneracies

```

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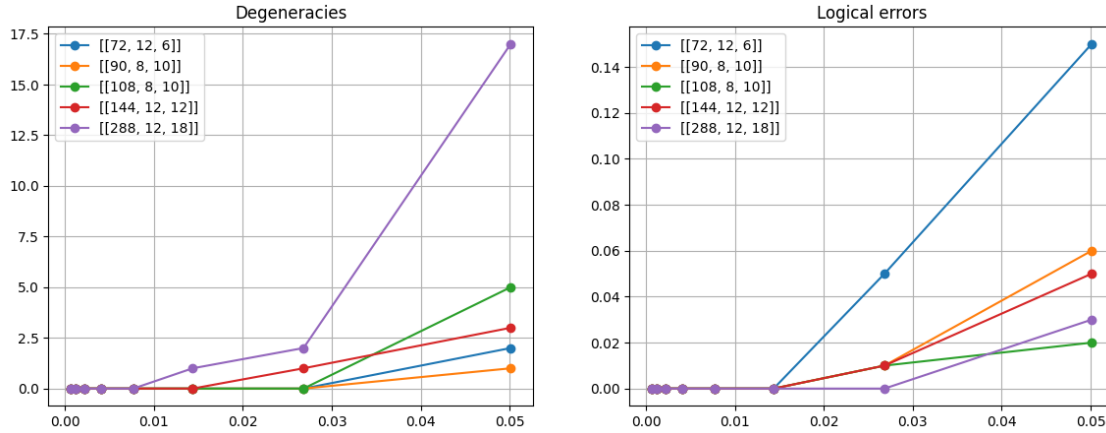
```

[75]: fig, axes = plt.subplots(1, 2, figsize=(14, 5))

for name in results_OSD:
    axes[0].plot(physicalErrorRates, results_OSD[name]['degeneracies'],
↪label=name, marker='o')
    axes[0].grid(True)
    axes[0].legend()
    axes[0].set_title('Degeneracies')

for name in results_OSD:
    axes[1].plot(physicalErrorRates, results_OSD[name]['ler'], label=name,
↪marker='o')
    axes[1].grid(True)
    axes[1].legend()
    axes[1].set_title('Logical errors')

```



```
[76]: plt.figure(figsize=(14, 6))
for i, name in enumerate(names):
    bps_fault = np.array(results_OSD[name] ['BPs_fault'])
    bps_misc = np.array(results_OSD[name] ['BPs_miscorrected'])
    incorrect = np.array(results_OSD[name] ['incorrectable'])
    positions = x + i * (bar_width + 0.02) # add small gap between bars

    if i == 0:
        plt.bar(positions, bps_fault, bar_width, label='BPs_fault', color='tab:
↪blue')
        plt.bar(positions, bps_misc, bar_width, bottom=bps_fault,
↪label='BPs_miscorrected', color='tab:orange')
        plt.bar(positions, incorrect, bar_width, bottom=bps_fault + bps_misc,
↪label='incorrectable', color='tab:green')
    else:
        plt.bar(positions, bps_fault, bar_width, color='tab:blue')
        plt.bar(positions, bps_misc, bar_width, bottom=bps_fault, color='tab:
↪orange')
        plt.bar(positions, incorrect, bar_width, bottom=bps_fault + bps_misc,
↪color='tab:green')

# Add code labels (n values) on top of each bar group
for i, name in enumerate(names):
    bps_fault = np.array(results_OSD[name] ['BPs_fault'])
    bps_misc = np.array(results_OSD[name] ['BPs_miscorrected'])
    incorrect = np.array(results_OSD[name] ['incorrectable'])
    total_height = bps_fault + bps_misc + incorrect
    positions = x + i * (bar_width + 0.02)

    for j, (pos, height) in enumerate(zip(positions, total_height)):
        if height > 0: # only label bars with data
```

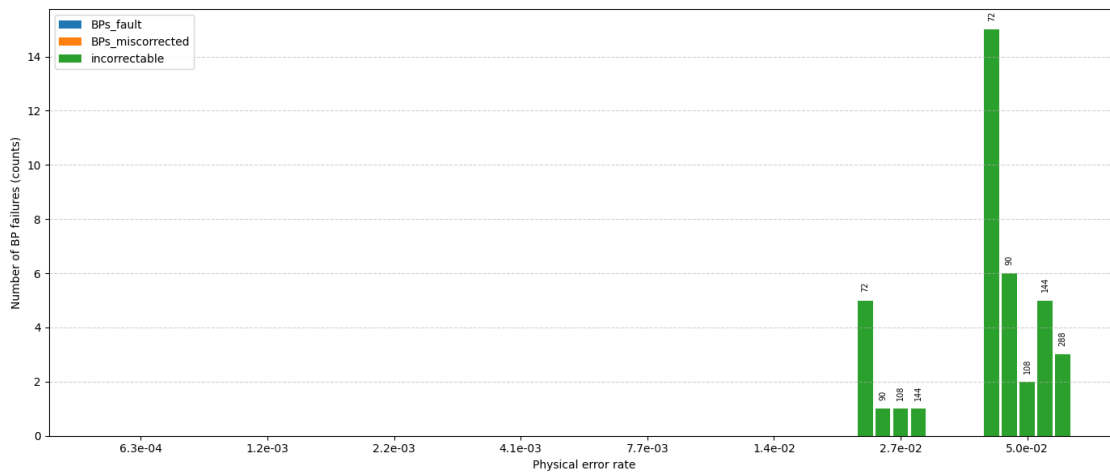


```

plt.text(pos, height + 0.3, code_labels[i], ha='center',
        ↪va='bottom', fontsize=7, rotation=90)

# center x-ticks under each group and format ticks
plt.xticks(x + (n_codes - 1) * (bar_width + 0.02) / 2, [f'{r:.1e}' for r in
        ↪physicalErrorRates])
plt.xlabel('Physical error rate')
plt.ylabel('Number of BP failures (counts)')
plt.grid(True, axis='y', linestyle='--', alpha=0.6)
plt.legend(loc='upper left')
plt.tight_layout()
plt.show()

```



```

[77]: fig, axes = plt.subplots(2, 2, figsize=(14, 5))

# Left plot: BP results
for name in results_BP:
    axes[0][0].plot(physicalErrorRates, results_BP[name]['degeneracies'],
        ↪label=name, marker='o')
axes[0][0].grid(True)
axes[0][0].legend()
# axes[0][0].set_xlabel('Physical error rate')
axes[0][0].set_xscale('log')
axes[0][0].set_ylabel('Degeneracies')
axes[0][0].set_title('BP degeneracy')

# Right plot: OSD results
for name in results OSD:
    axes[1][0].plot(physicalErrorRates, results OSD[name]['degeneracies'],
        ↪label=name, marker='o')

```

```

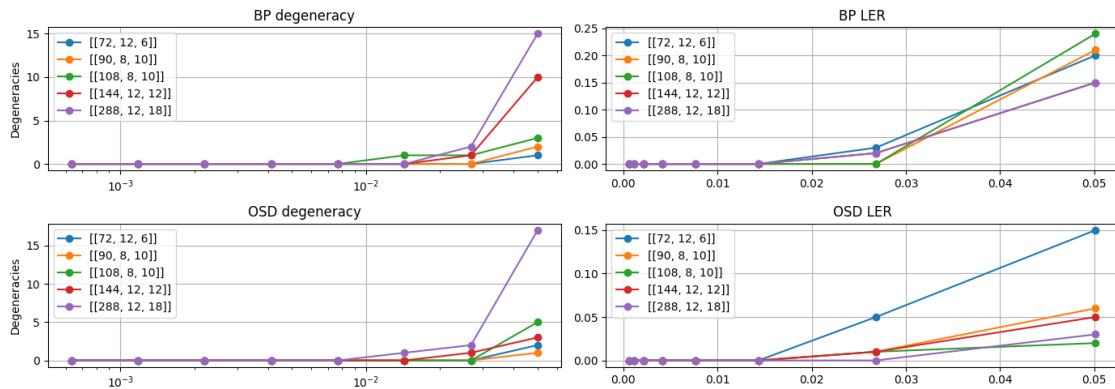
axes[1][0].grid(True)
axes[1][0].legend()
# axes[1][0].set_xlabel('Physical error rate')
axes[1][0].set_xscale('log')
axes[1][0].set_ylabel('Degeneracies')
axes[1][0].set_title('OSD degeneracy')

for name in results_BP:
    axes[0][1].plot(physicalErrorRates, results_BP[name]['ler'], label=name,
        ↪marker="o")
axes[0][1].grid(True)
axes[0][1].set_title("BP LER")
axes[0][1].legend()

for name in results_OSD:
    axes[1][1].plot(physicalErrorRates, results_OSD[name]['ler'], label=name,
        ↪marker="o")
axes[1][1].grid(True)
axes[1][1].set_title("OSD LER")
axes[1][1].legend()

plt.tight_layout()
plt.show()

```

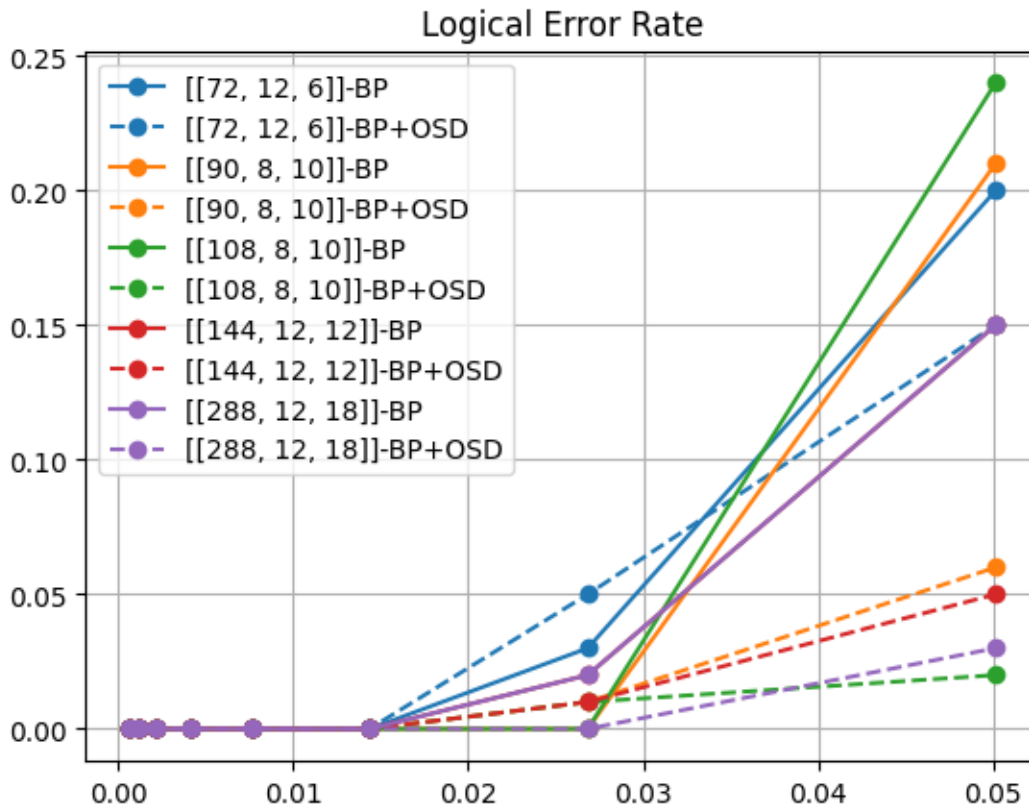


```

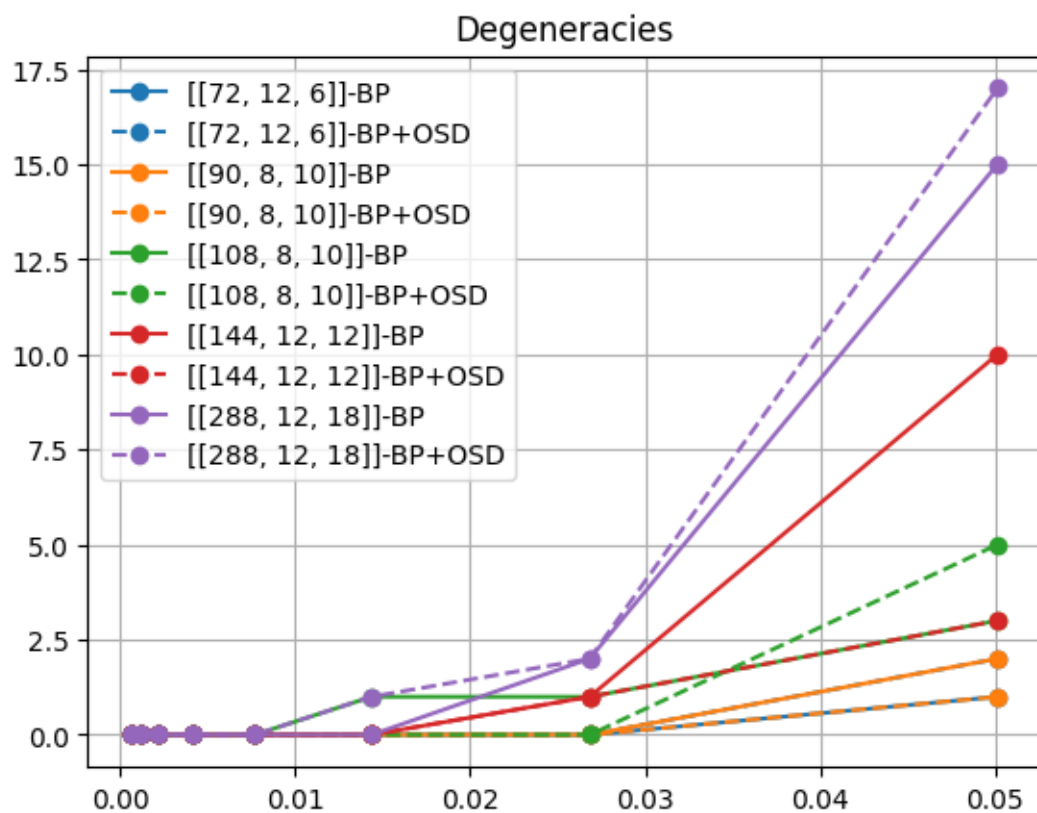
[78]: colors = plt.rcParams['axes.prop_cycle'].by_key()['color']
for i, name in enumerate(results_BP):
    c = colors[i % len(colors)]
    plt.plot(physicalErrorRates, results_BP[name]['ler'], label=f"{name}-BP",
        ↪marker='o', color=c)
    plt.plot(physicalErrorRates, results_OSD[name]['ler'],
        ↪label=f"{name}-BP+OSD", marker='o', linestyle='dashed', color=c)
plt.legend()

```

```
plt.grid(True)
plt.title("Logical Error Rate")
plt.show()
```



```
[79]: colors = plt.rcParams['axes.prop_cycle'].by_key()['color']
for i, name in enumerate(results_BP):
    c = colors[i % len(colors)]
    plt.plot(physicalErrorRates, results_BP[name]['degeneracies'],
             label=f"{name}-BP", marker='o', color=c)
    plt.plot(physicalErrorRates, results_OSD[name]['degeneracies'],
             label=f"{name}-BP+OSD", marker='o', linestyle='dashed', color=c)
plt.legend()
plt.grid(True)
plt.title("Degeneracies")
plt.show()
```



[ ]: