Investigating Φ

Angus Leung

2017-07-28

Overview

- Integrated Information Φ

- 2 investigations:
  - Air vs isoflurane Φ
  - Φ vs Φ*

Axioms of Integrated Information Theory

- Existence
- Composition
- ***Information*****:** out of all the experiences we can **possibly** have at any time (uncertainty), at any time we only experience **one** (reduction in uncertainty)
- ***Integration*****:** we cannot separate an experience into parts (binding problem: we don't see red and a ball; we see a red ball)
- Exclusion

Consciousness and Integration/Information

- Loss of consciousness (e.g. NREM sleep, anaesthesia) has been associated with loss of information or integration
  - e.g. stereotyped responses to stimuli
  - e.g. reduced effective connectivity, feedback

- But what about Φ?
  - IIT: Φ is consciousness (there's a bit more to Φ)
  - Loss of consciousness <-> loss of Φ

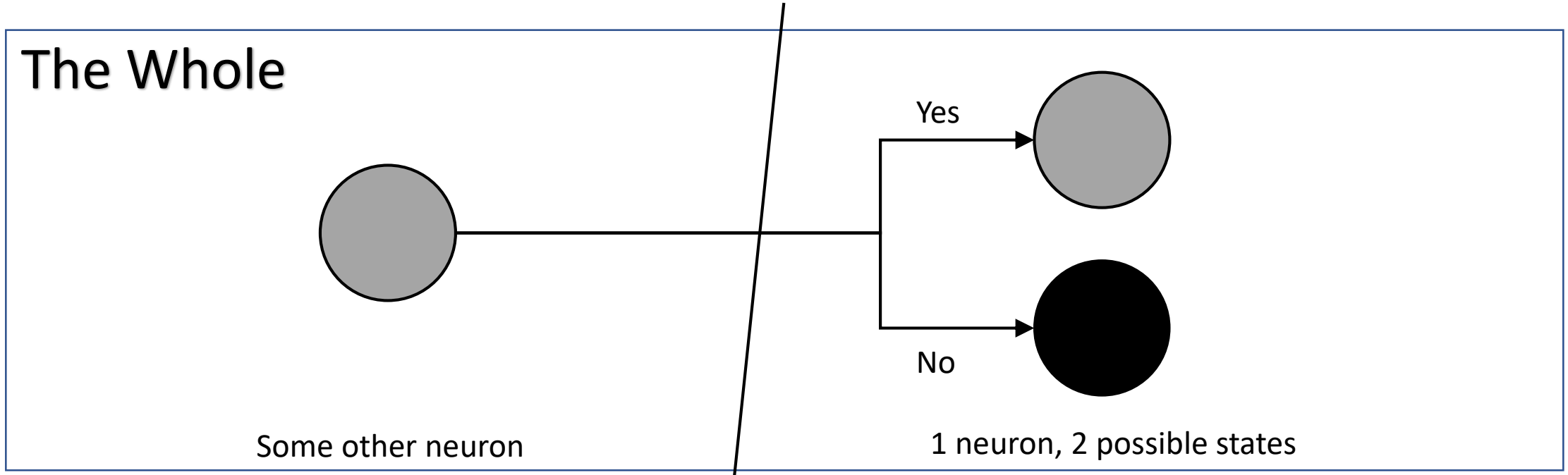
What is Integrated Information Φ?

Integrated O

- O = exists only when considering the whole
- O = reduction due to splitting

Information |

- I = reduction in uncertainty
- Uncertainty: a neuron can be firing or not firing



What is Integrated Information Φ?

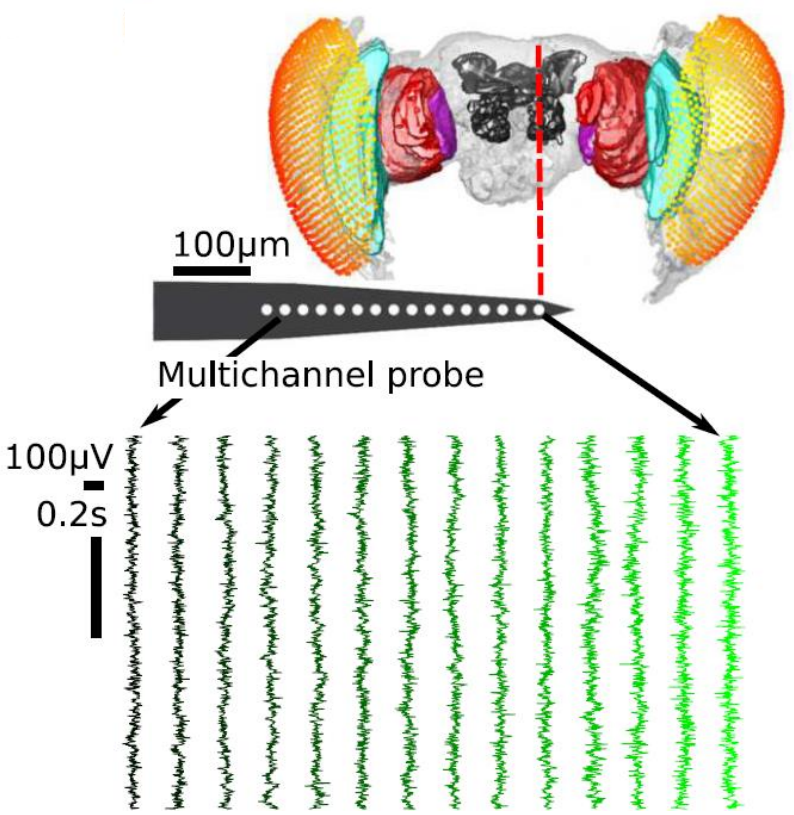
- Does a given a network state (e.g. state of all neurons in the brain) constrain the possible **past** and **future** network states?
  - Yes – constrained states = reduced uncertainty = information
  - No – states unconstrained = same uncertainty = no information

- Does splitting the network (e.g. brain into two hemispheres) give us the same information as not splitting the network?
  - Yes – no integration
  - No – integration is a vital part of the system – difference in information is Φ

Data

Fly Data

- 13 fruit flies (*Drosphila melanogaster*)
- Half-brain probe: 16 electrodes
  - 15 ‘channels’ after bipolar re-referencing
- 2 conditions:
  - 0% isoflurane (air)
  - 0.6% isoflurane (iso)
- 18s of ‘spontaneous’ LFP
  - 18s period after an air puff
  - 18s period split into 8 x 2.25s trials, 1kHz sampling rate (downsampled from 25kHz)

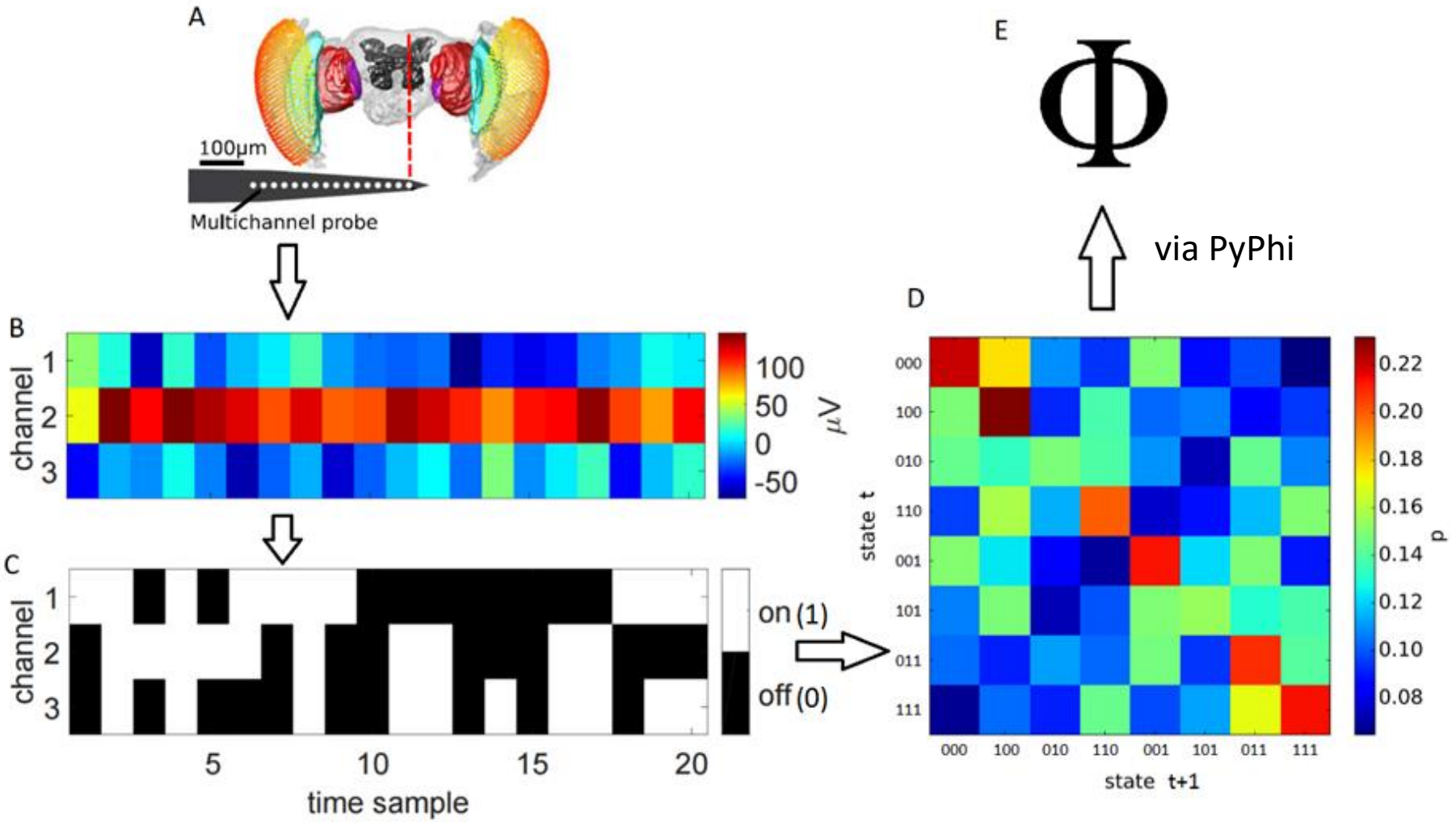


Φ Parameters

- Number of channels: 2 to 4 (all combinations)
  - 15 choose 2 = 105 sets
  - 15 choose 3 = 455 sets
  - 15 choose 4 = 1365 sets

- Time lag (τ): 4ms, 8ms, 16ms
  - TPM for 4ms: for a state at sample t, probability of sample t+4 being a specific state
  - Exclusion axiom: consciousness flows at a particular speed (where Φ is max)

Φ Calculation



Air vs Isoflurane

Investigation 1

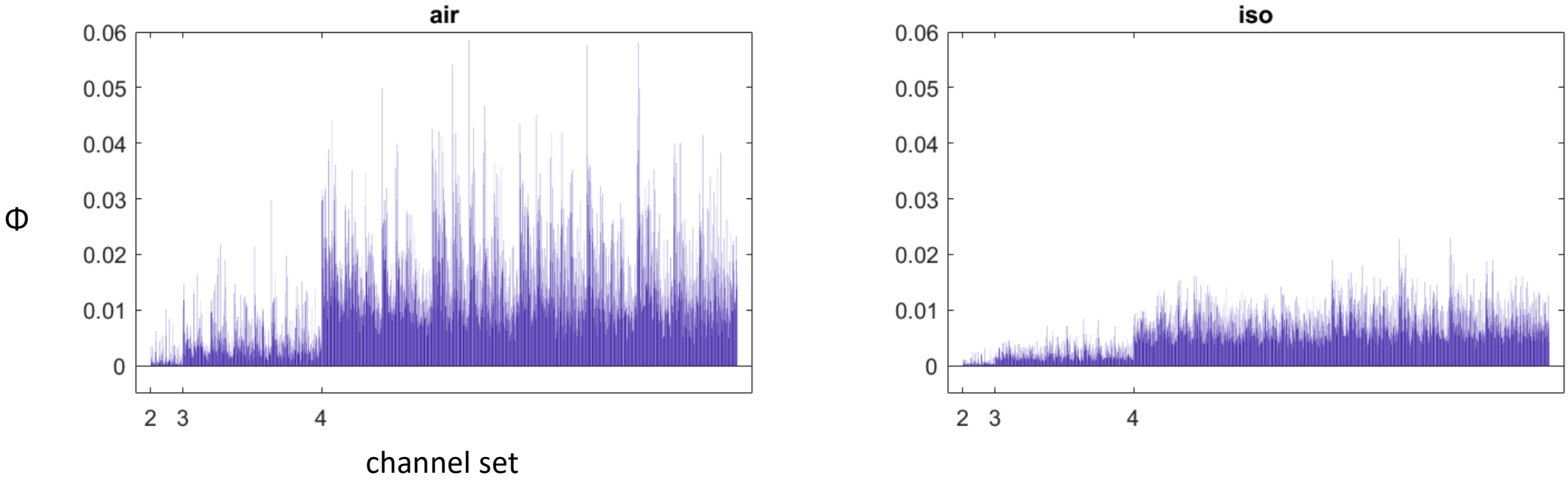
Investigation 1: air vs isoflurane

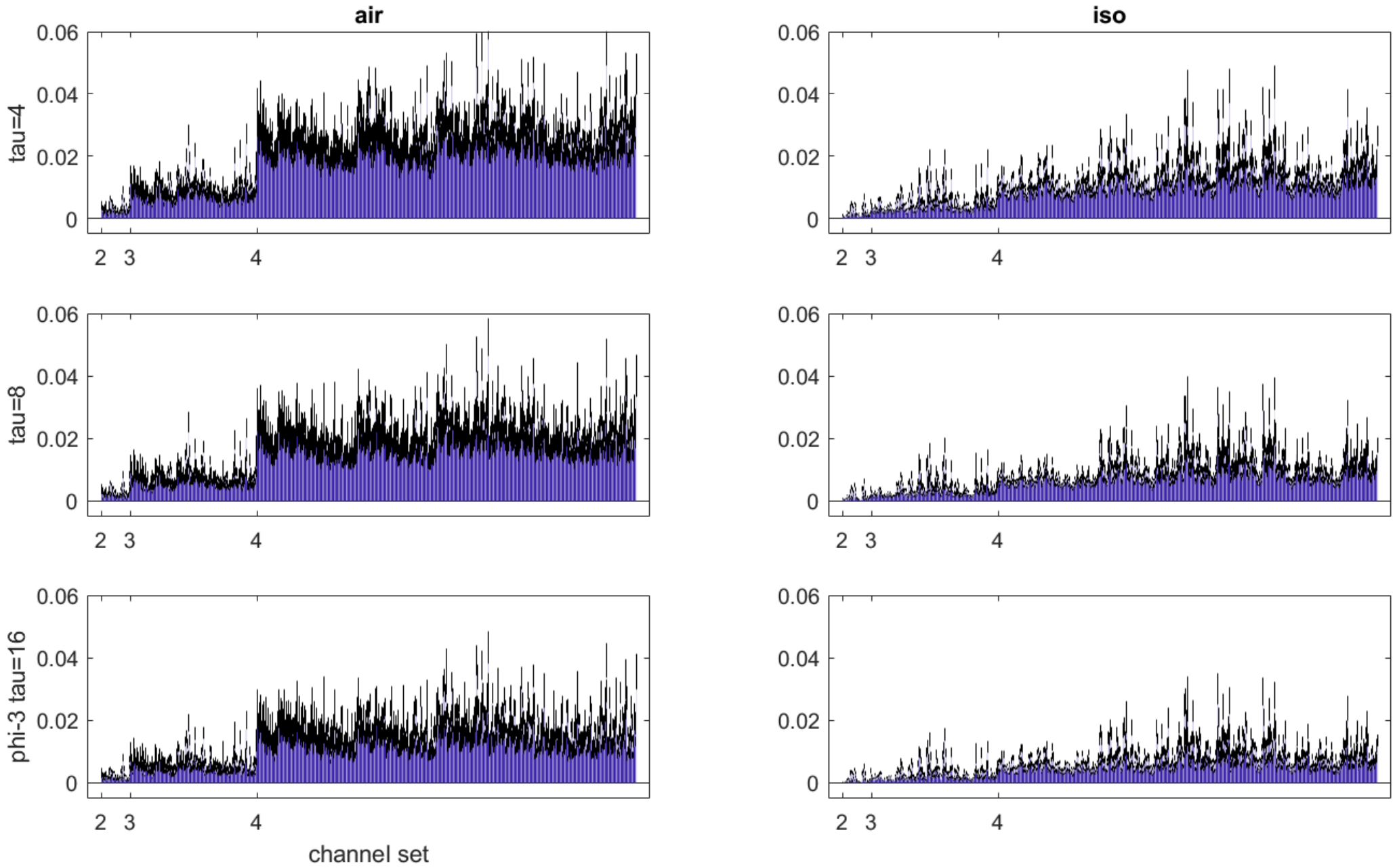
- Is Φ lower during anaesthesia?

- Simplest prediction of IIT:
  - Loss of consciousness = loss of Φ
  - If a system loses consciousness, Φ should be lower

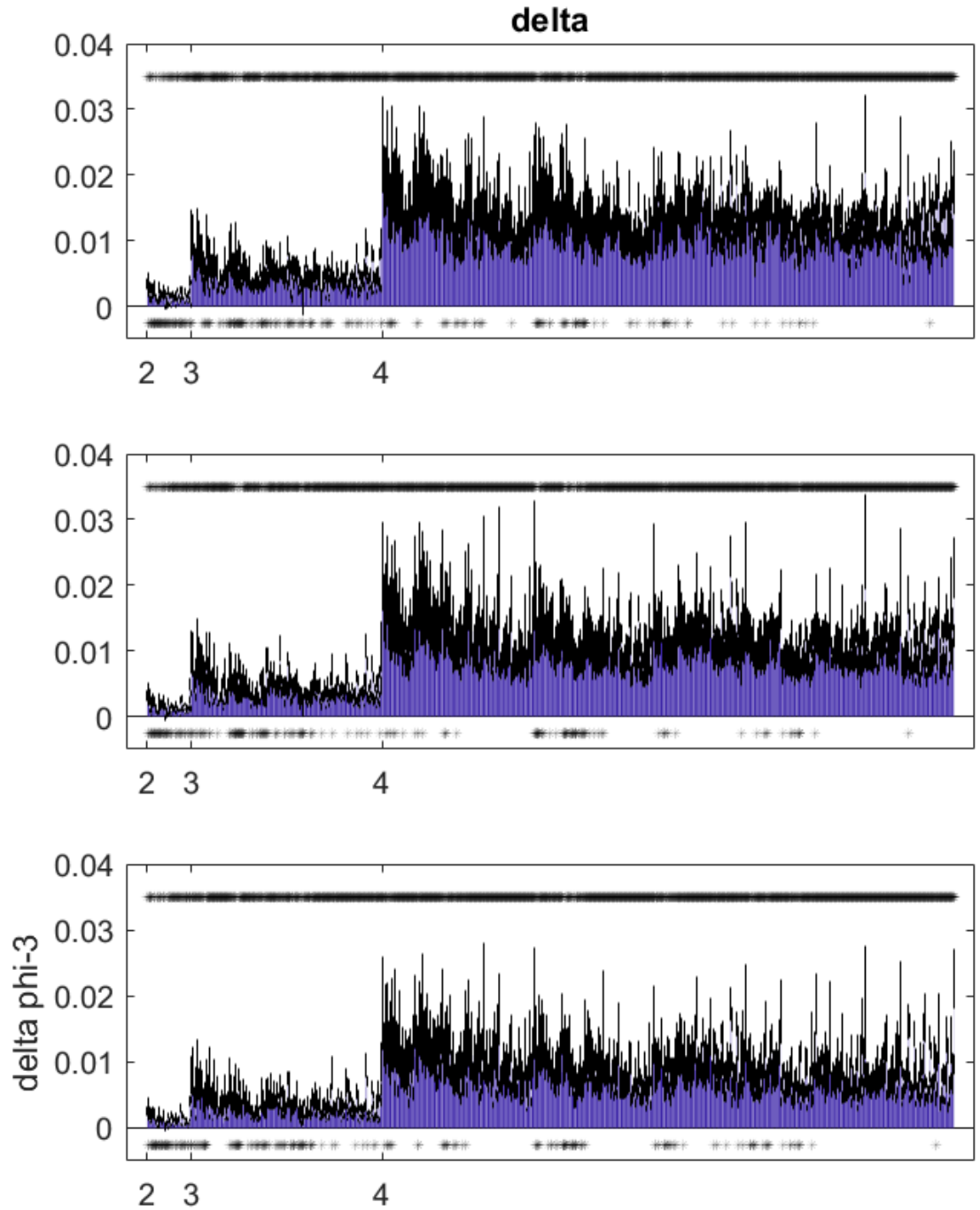
- Here we presume that flies are conscious under air, and lose consciousness under iso
  - Movement responses to air puffs diminished under anaesthesia

Φ values for 1 fly, lag=4ms




air
iso
tau=4
tau=8
phi-3 tau=16
0.06
0.04
0.02
0
2
3
4
channel set

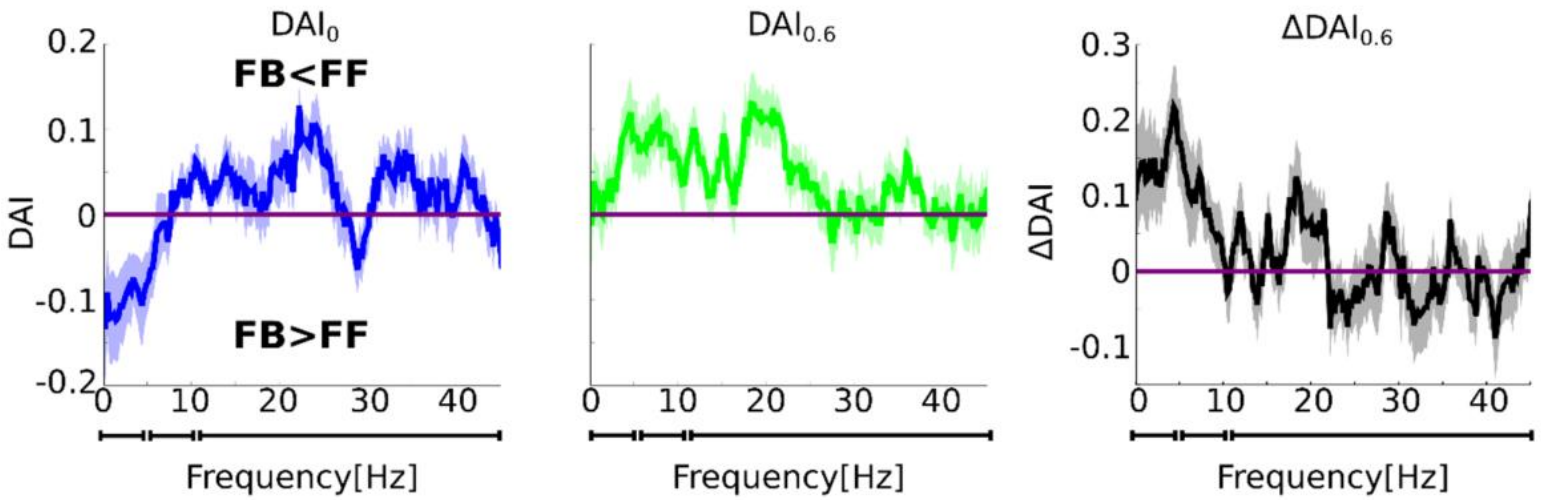
delta = air - iso



Past finding: reduced feedback under iso

- Past finding on same dataset using Granger Causality:
  - Feedback reduced under anaesthesia, for low frequencies
  - Feedback: centre channel -> periphery channel
- GC: one signal contains information about another

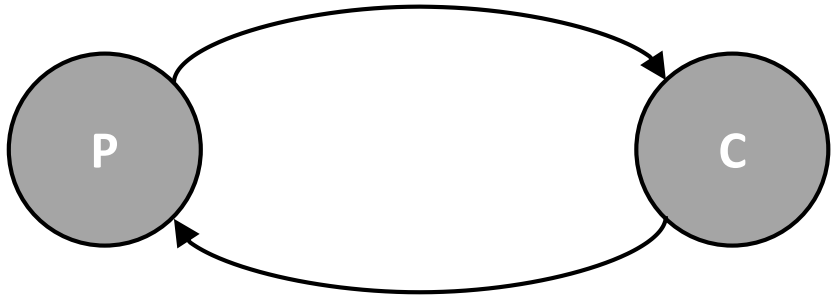
$$DAI = \frac{FF - FB}{FF + FB}$$



Is feedback reduction captured in the MIP?

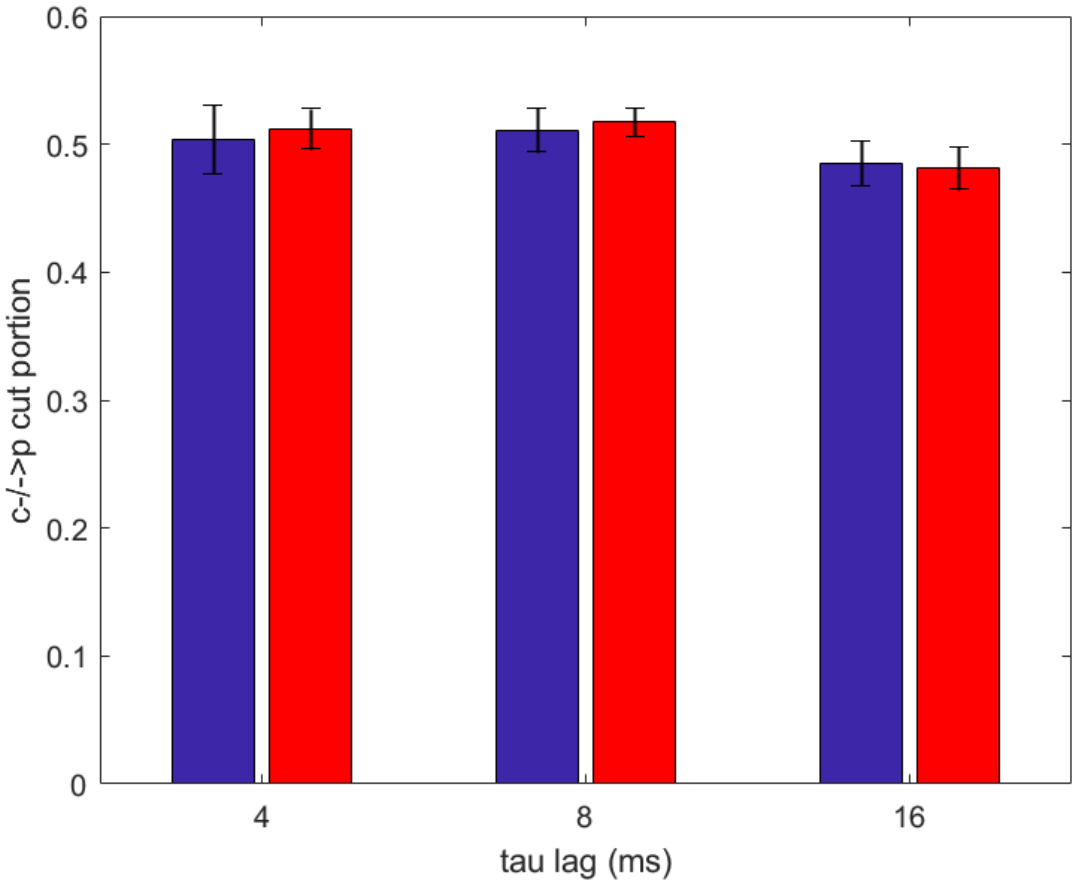
- The minimum information partition (MIP) is the unidirectional split which results in the least difference in information
  - No difference -> integration not vital among the split parts
  - MIP reduces the system as much as possible to independent parts
- If feedback loses importance, then cutting this connection should give a smaller difference
  - So the centre -> periphery cut might be more common under isoflurane

- 2 channel scenario:

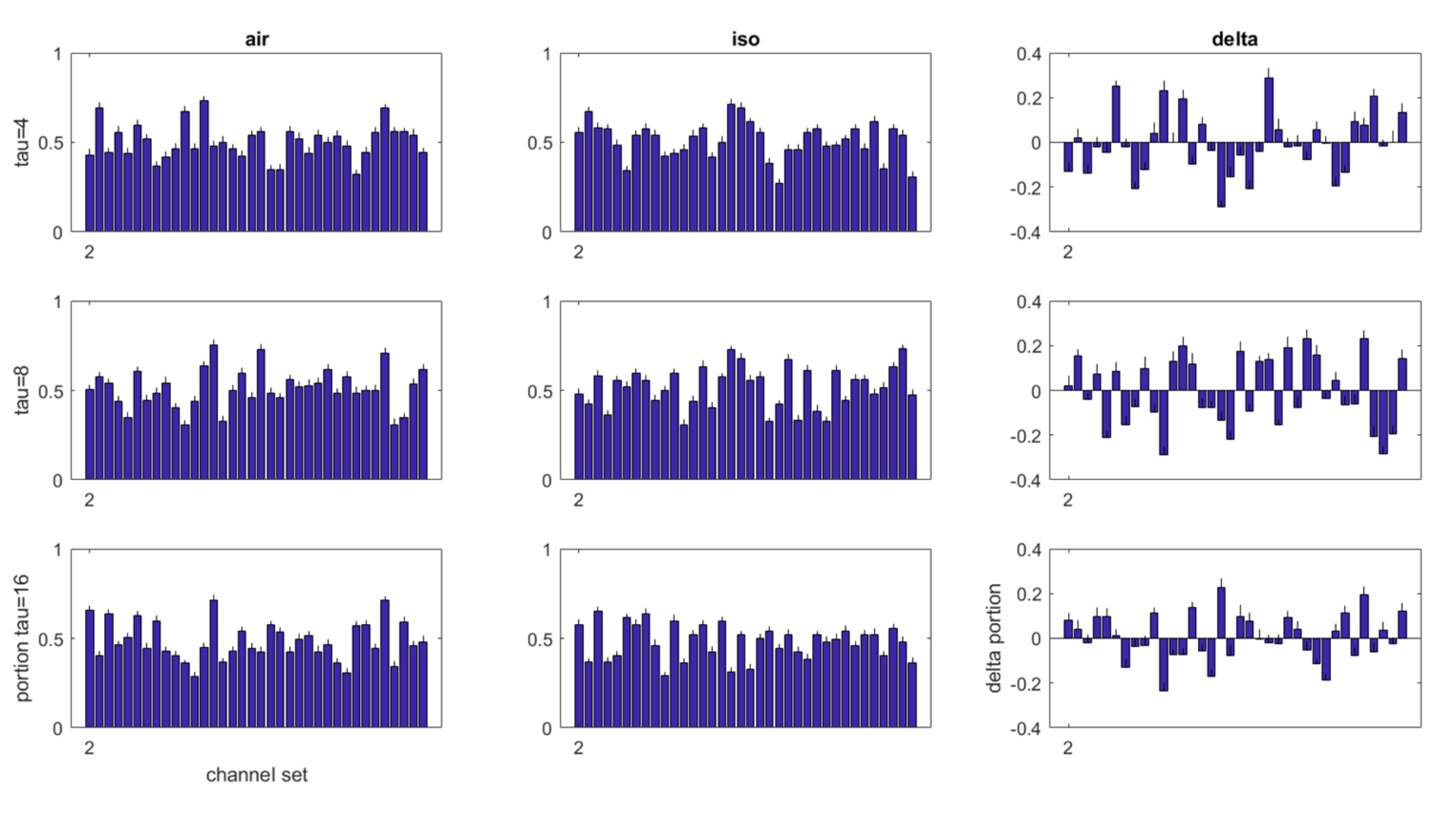


Portion of c-/->p cuts

- 2 channels = 4 states
- Portion of samples within a trial with a feedback cut as the MIP



B: air
R: iso


air
iso
delta
tau=4
tau=8
portion tau=16
delta portion
channel set
1
0.5
0
0.4
0.2
-0.2
-0.4
2

Φ vs Φ*

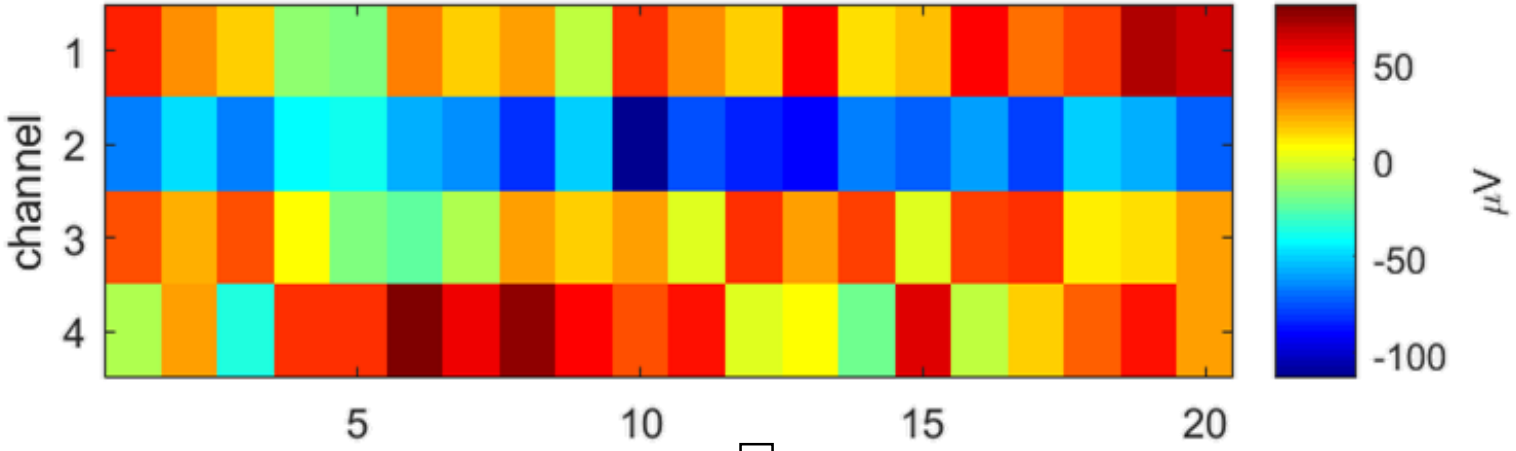
Investigation 2

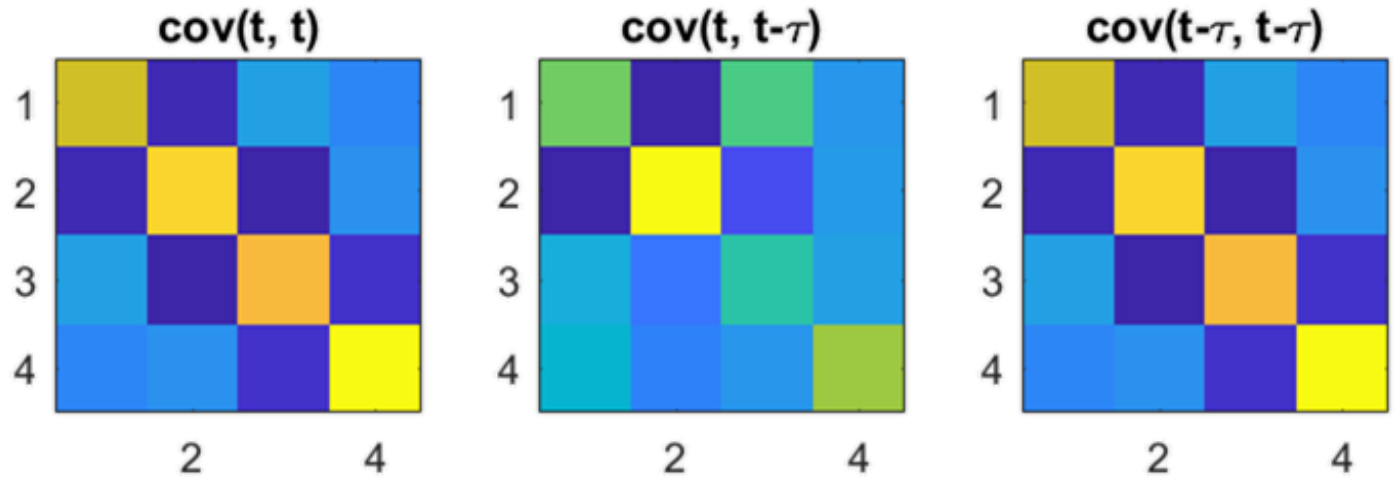
Investigation 2: Φ* vs Φ

- Φ computation is resource intensive
- Φ* can be analytically computed using the Gaussian approximation (this means faster computation)

- Φ* based on IIT 2.0
- Slight differences between IIT 2.0 and IIT 3.0
  - IIT 2.0 assesses how a state constrains a system's past; IIT 3.0 assesses also how it constrains the future (more complex)
  - Φ*: symmetry between past-present and present-future

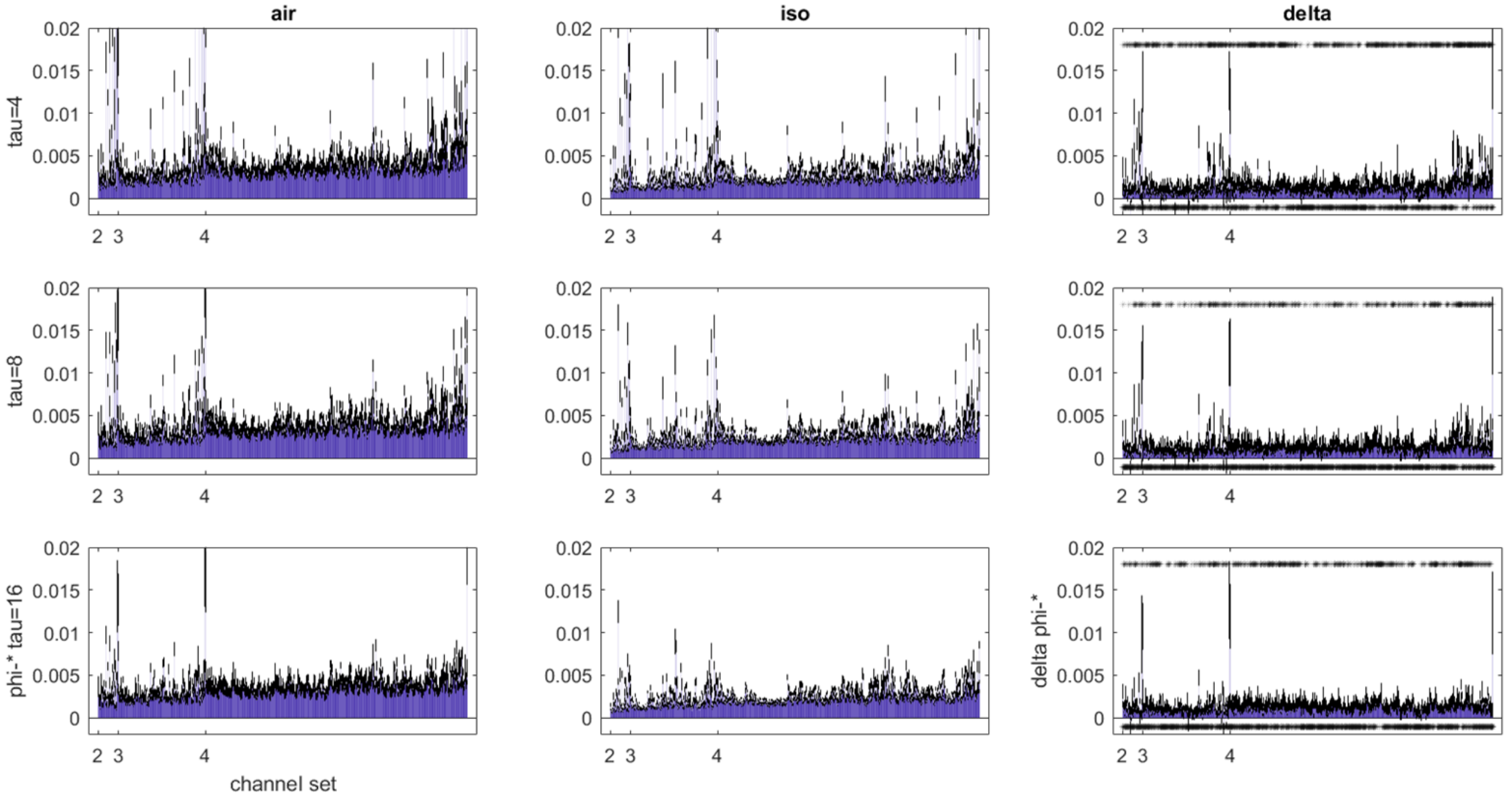
Φ* Calculation





Φ*

via phi_toolbox_Feb2014
(Haun et al., 2016)


air
iso
delta
tau=4
tau=8
phi-* tau=16
delta phi-*
0.02
0.015
0.01
0.005
0
2 3 4
channel set

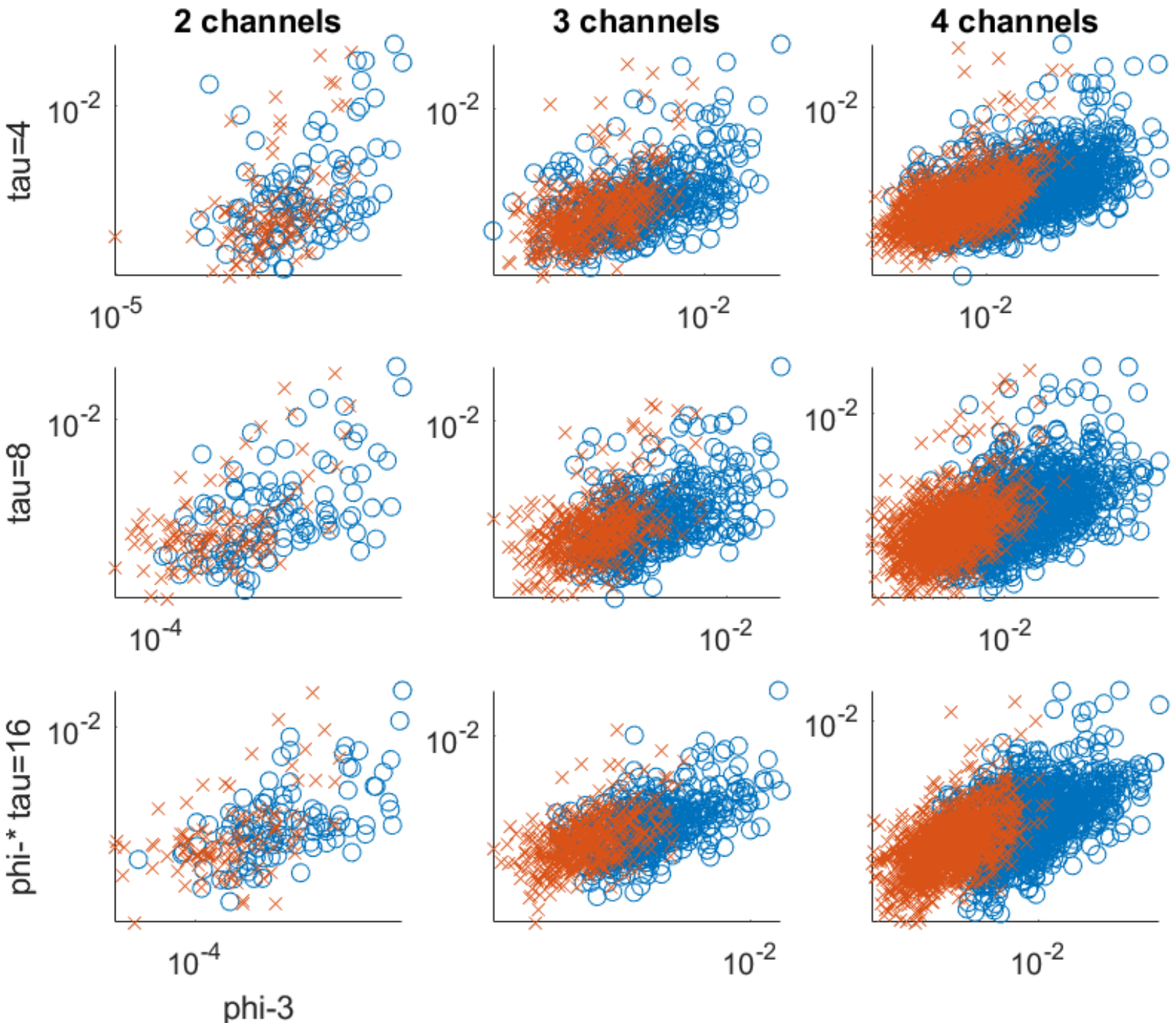
Comparing Φ* to Φ

- Do they increase/decrease together?

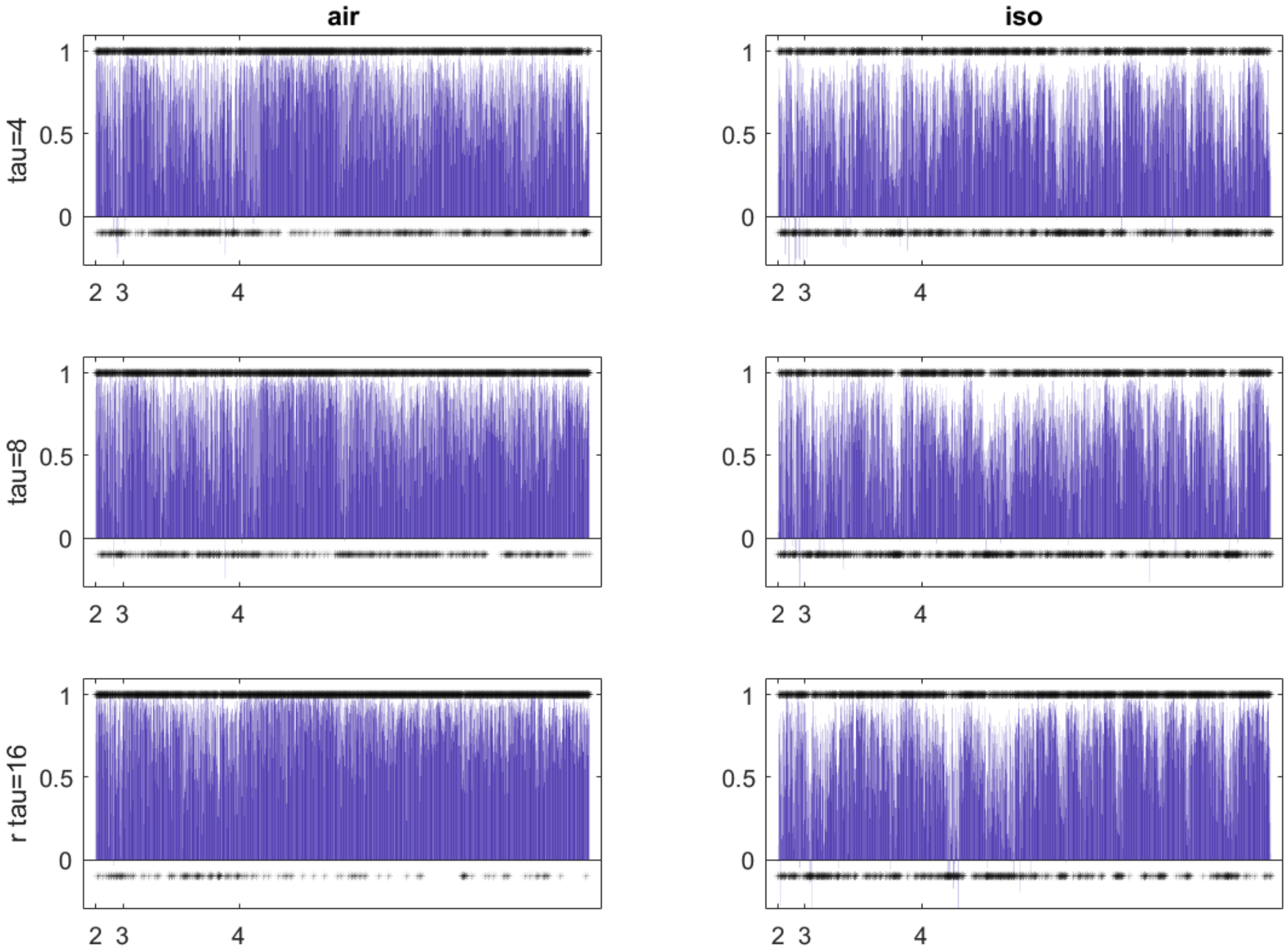
- Do they give equivalent MIPs?

Φ-Φ* correlations for 1 fly

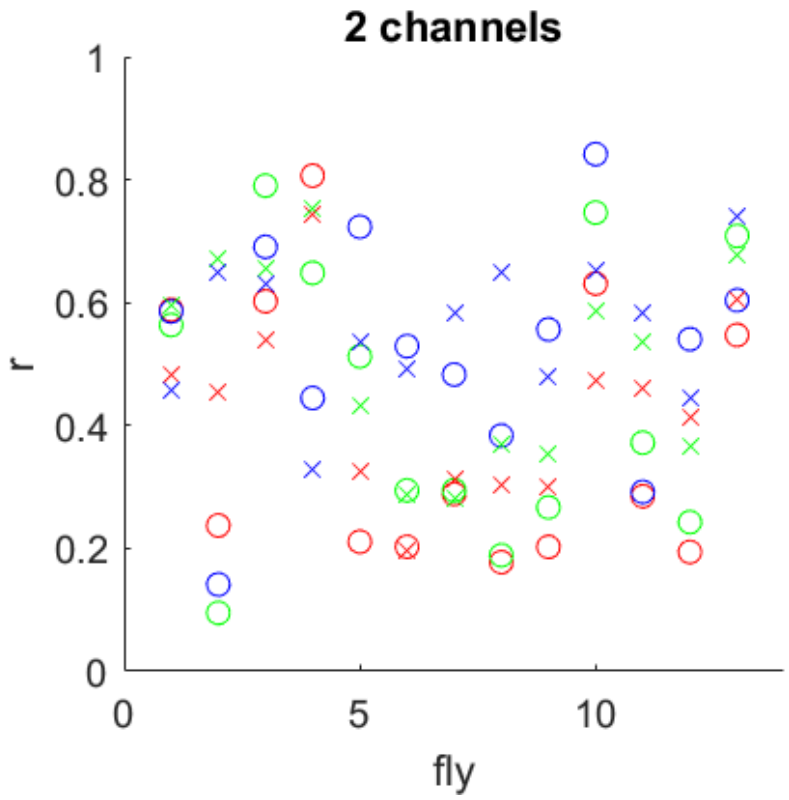
o: air
x: iso

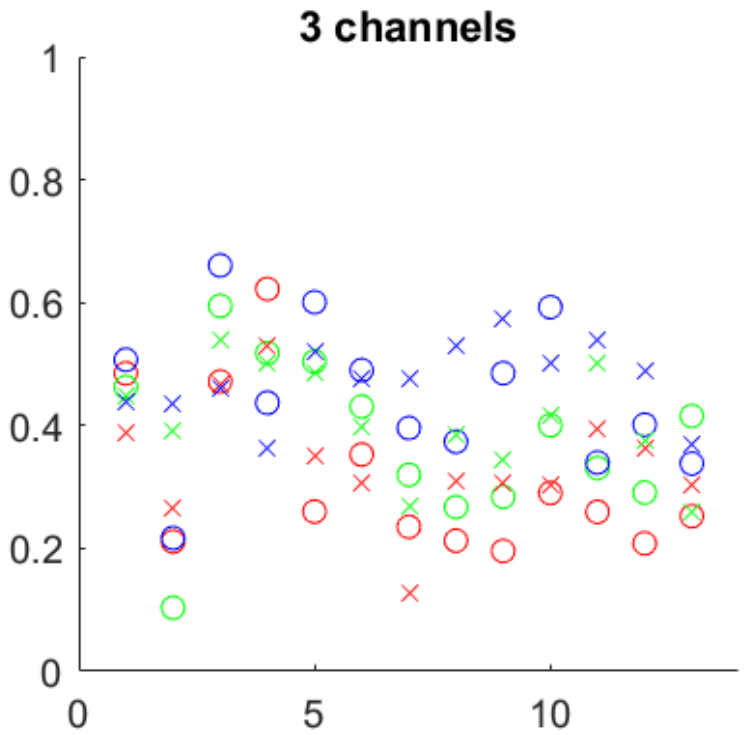


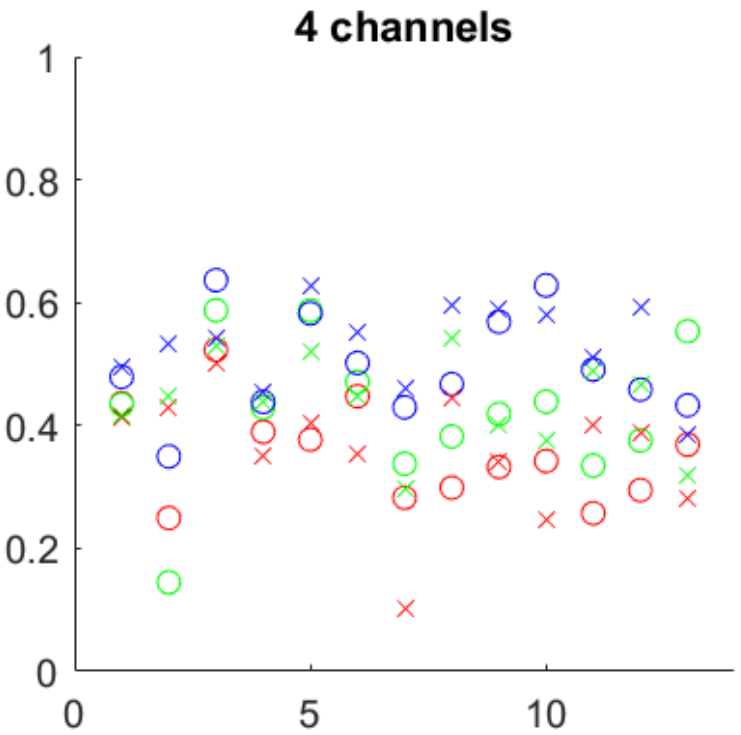
Correlations for each channel set



Correlations for each fly







R: tau=4ms G: tau=8ms B: tau=16ms

Difference between Φ and Φ* MIPs

- IIT 3.0: MIPs are bipartitions from unidirectional cuts
  - Directional: A-/->B is different to B-/->A
  - Separated partitions can be considered appendages

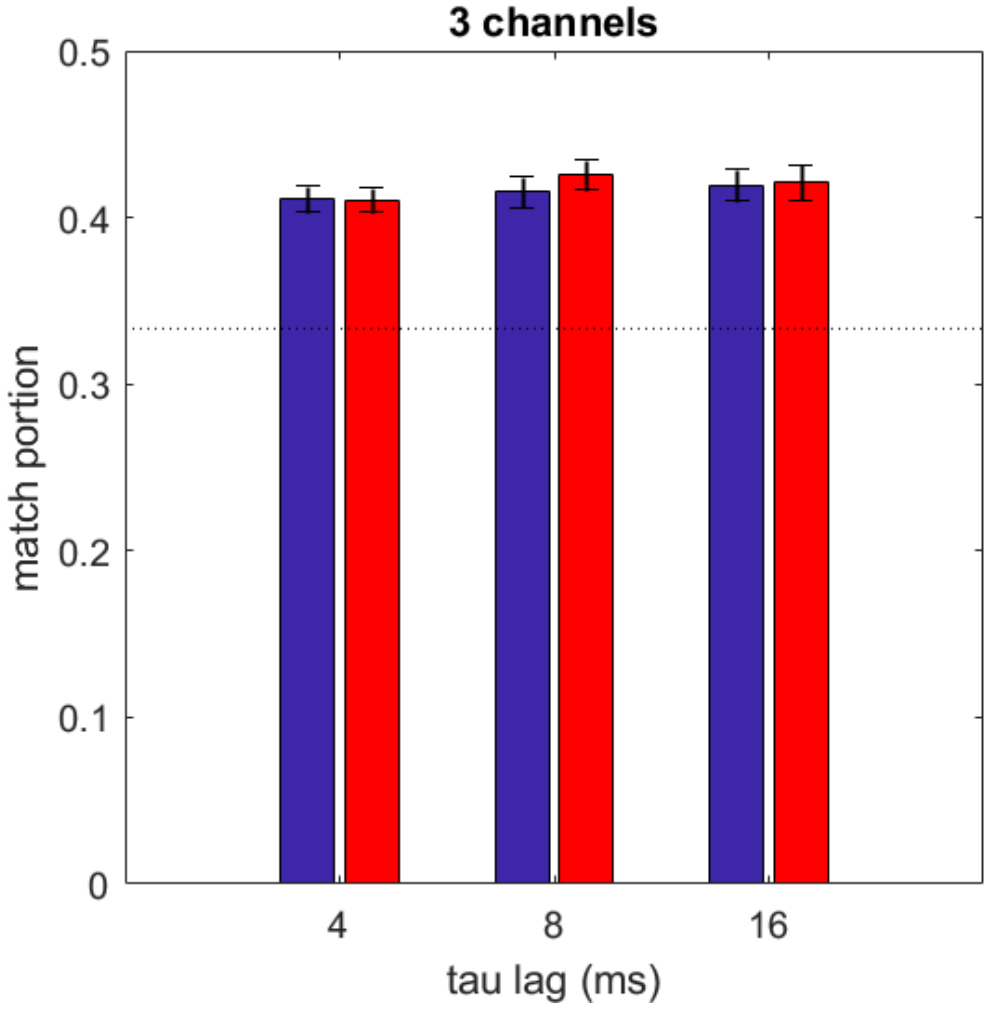
- Φ* MIPs are non-directional
  - IIT 2.0 only considers the past and present (symmetrically in Φ*)
  - Cut connections leave partitions completely isolated

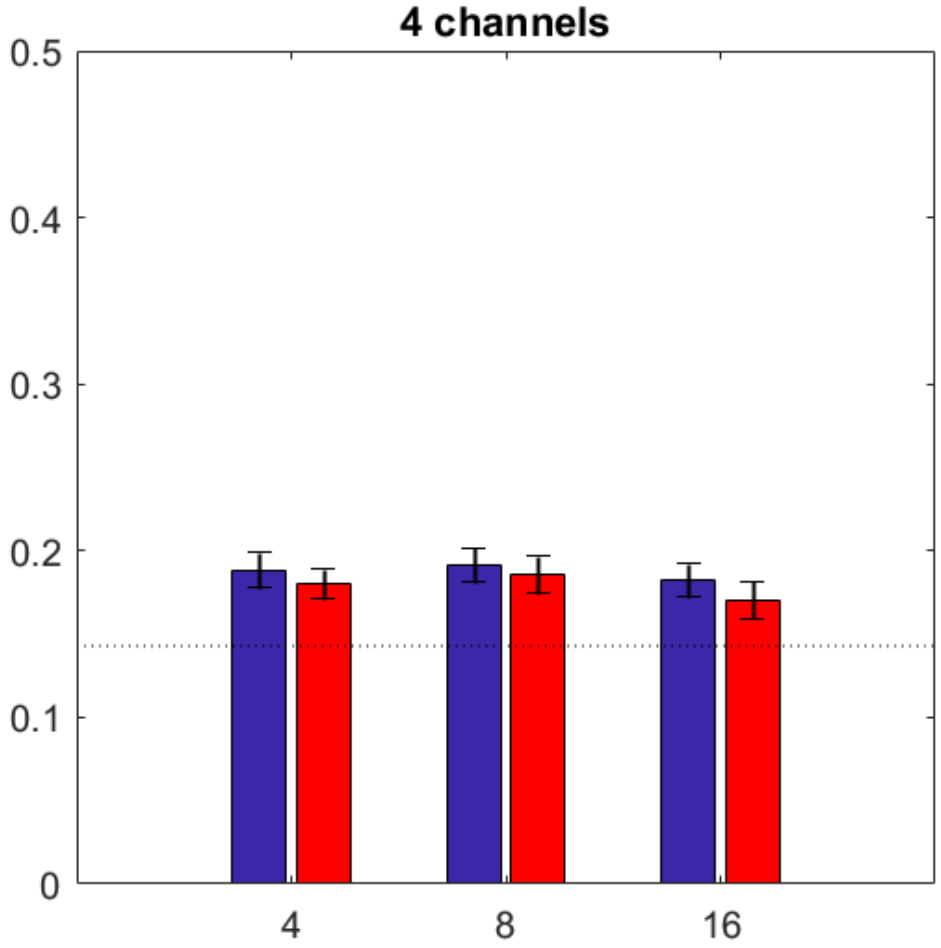
- Φ* MIPs are not limited to bipartitions

MIP Matching

- For comparison, ignore directionality of Φ MIPs
- For comparison, only consider Φ* MIPs which are bipartitions
- Reminder: only one Φ* MIP per trial, but multiple Φ MIPs

Portion of matching MIPs





Conclusions

- Clearest prediction of IIT met
- Reduced feedback not captured by MIP cuts
  - May be due to building the TPM once per condition
- Moderate correlations between Φ and Φ*
  - Slightly stronger for larger τ
  - Likelihood of MIPs matching slightly higher than chance

- Future direction: Use TPM built across both conditions to calculate Φ
- Future direction: calculate Φ* using discretised values