



# CORTEX

Core monitoring techniques and  
experimental validation and demonstration

# Results and lessons learned

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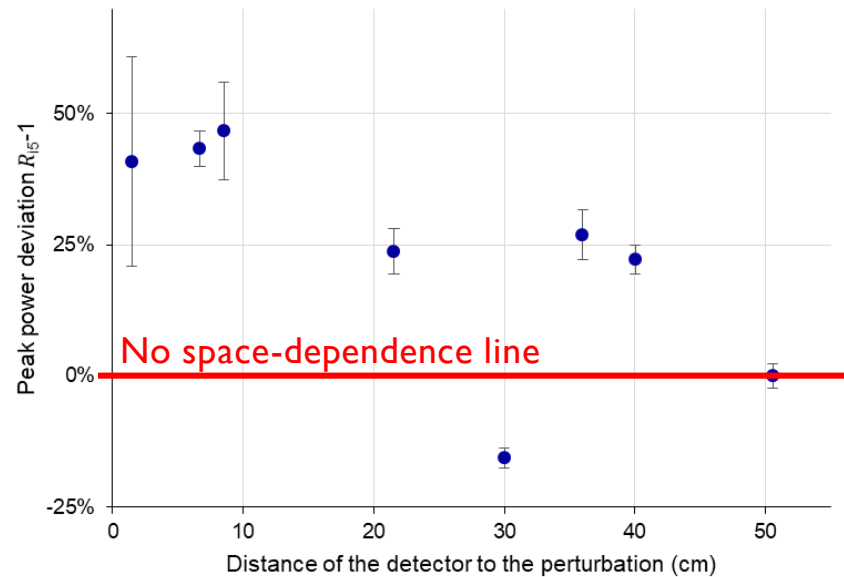
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- Early results of 1<sup>st</sup> campaign
- Preliminary results of 2<sup>nd</sup> campaign
- Lessons learned

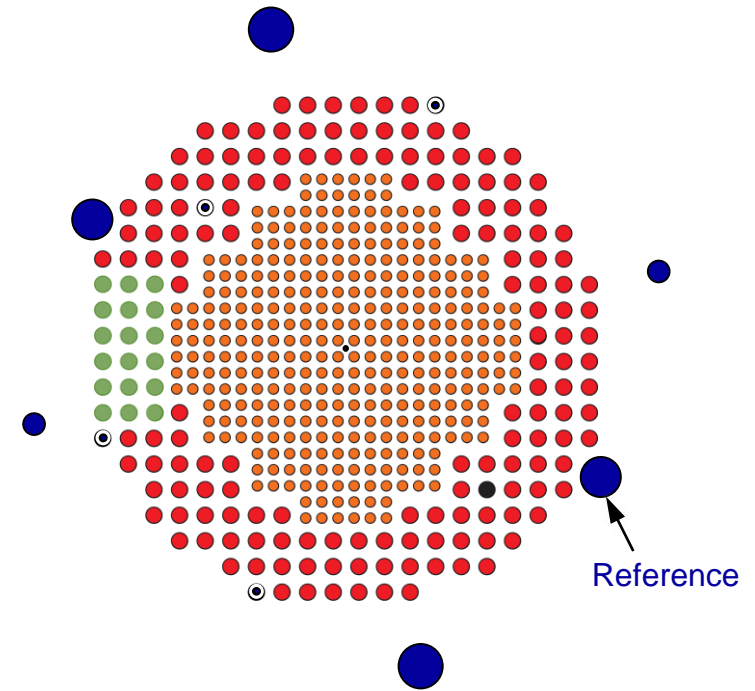


# Early results of 1<sup>st</sup> campaign

A spatial dependence was observed!



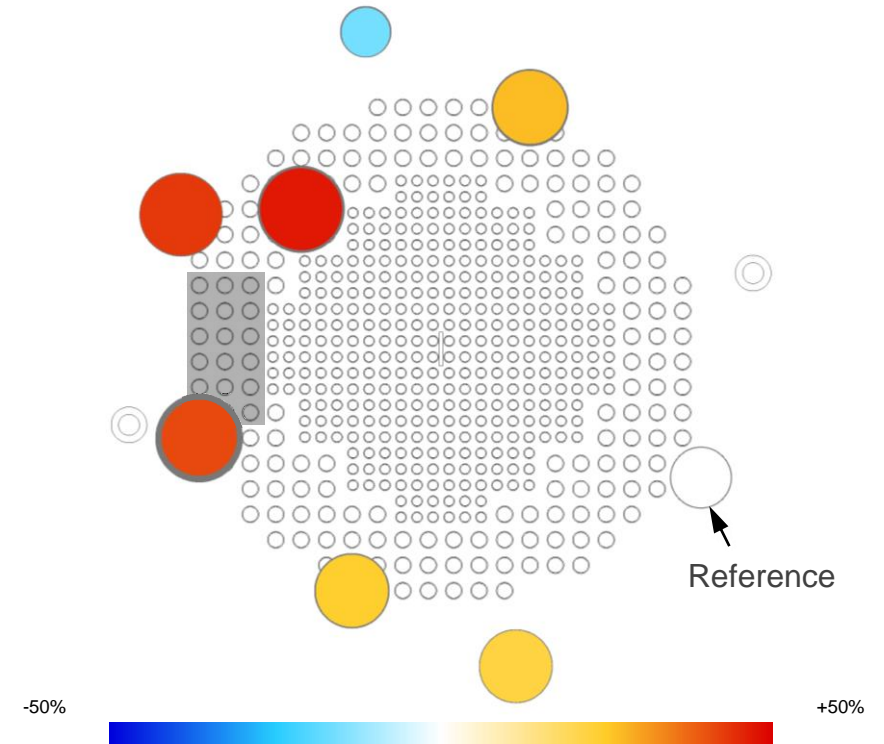
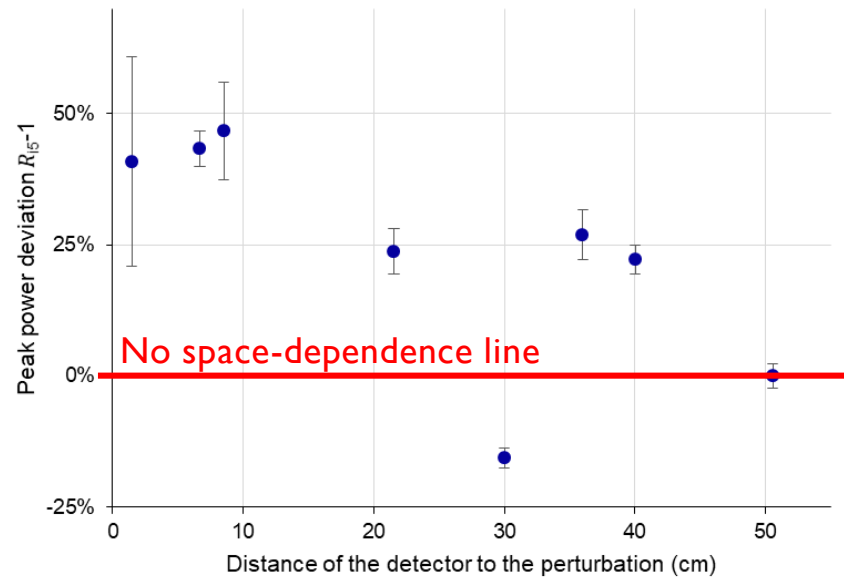
**Results in relative noise powers,**  
as a function of distance to the perturbation  
(18 rods at  $\pm 1.5$  mm and 0.1 Hz)



Configuration of the first experimental campaign,  
with perturbation in green and detectors in blue

# Early results of 1<sup>st</sup> campaign

A spatial dependence was observed!<sup>1</sup>



**Results in relative noise powers**, as a function of distance to the perturbation (left), and on a cross section of CROCUS (disks) (18 rods at  $\pm 1.5$  mm and 0.1 Hz)

<sup>1</sup> V. Lamirand et al., "Analysis of the first COLIBRI fuel rods oscillation campaign in the CROCUS reactor for the European project CORTEX," EPJ Web Conf., vol. 247, p. 21010, Feb. 2021.



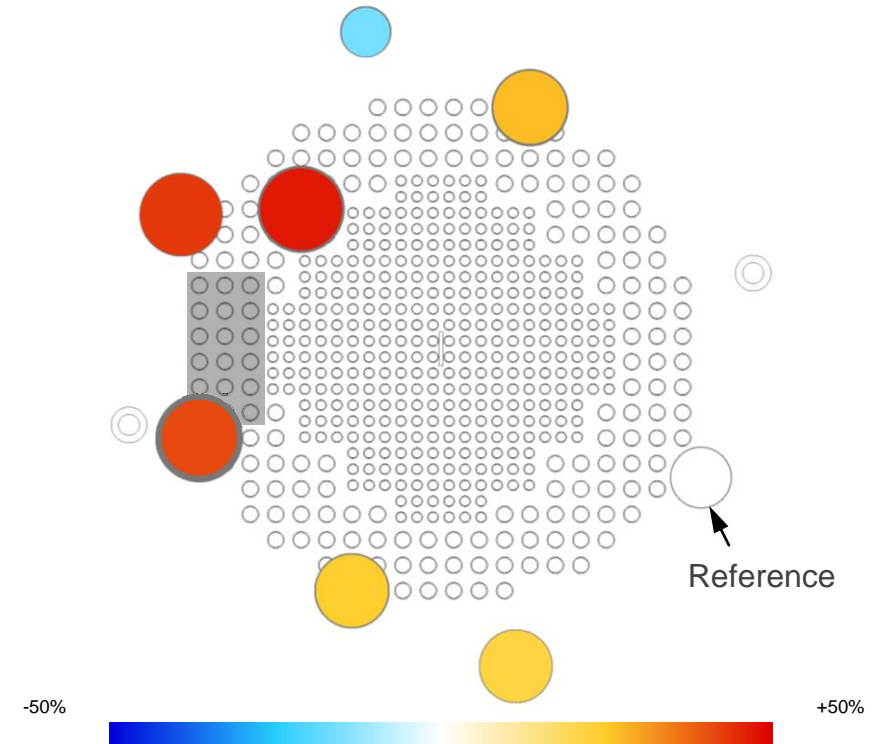
# Early results of 1<sup>st</sup> campaign

A spatial dependence was observed!<sup>1</sup>

- Noise level not following the flux map
- Accessible within the uncertainties

... with limitations & inconsistencies:

- **Outliers** & repeatability issues
- Resolution uncertainty not considered
- Correlations not taken into account



Results in relative noise powers on a cross section of CROCUS (disks) (18 rods at  $\pm 1.5$  mm and 0.1 Hz)

<sup>1</sup> V. Lamirand et al., "Analysis of the first COLIBRI fuel rods oscillation campaign in the CROCUS reactor for the European project CORTEX," EPJ Web Conf., vol. 247, p. 21010, Feb. 2021.



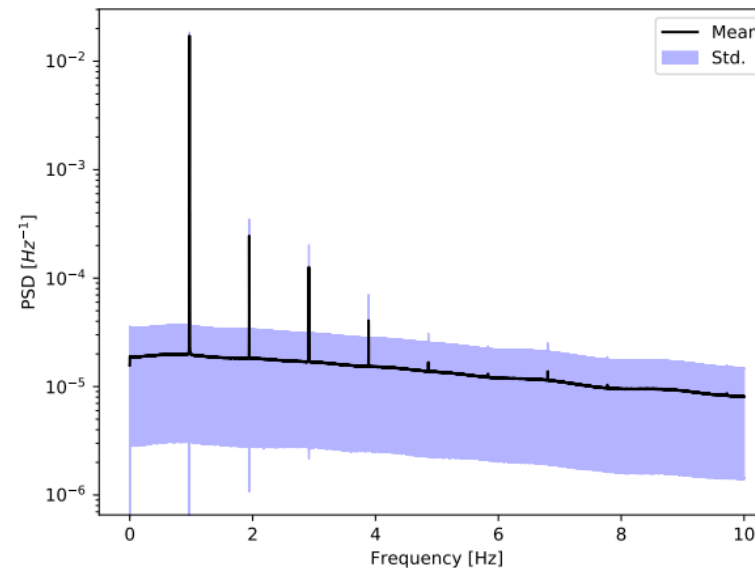
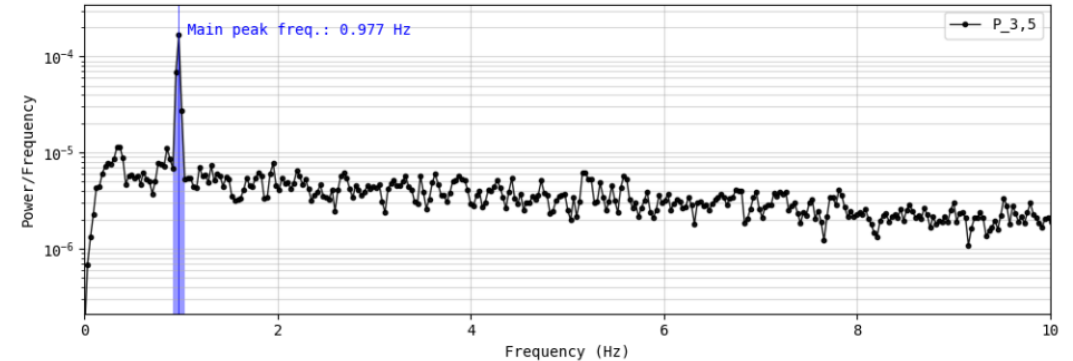
# Improved 1<sup>st</sup> campaign analysis methodology

Bootstrapping instead of usual (naive) PSD estimate

- PSD base frequency results consistent with old evaluations.
- Phase angles resolved (also base freq.)!
- Increased prominence at higher harmonic frequencies.

... some issues were also identified:

- Repeatability issues
- Frequency variations in COLIBRI: longer measurements required!
- Uncertainty calculated from multiple ratio evaluations (not propagated from ground up)



Old (top) and new (left) power spectral density evaluation between detectors 3 & 5



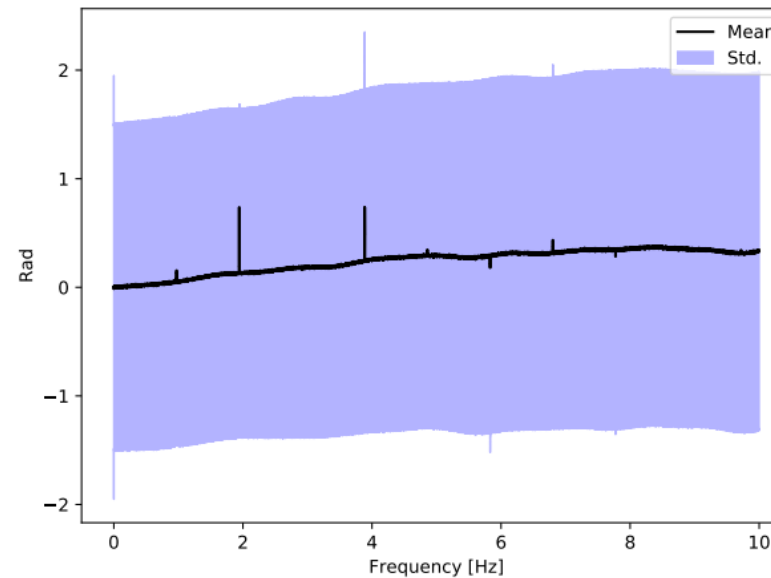
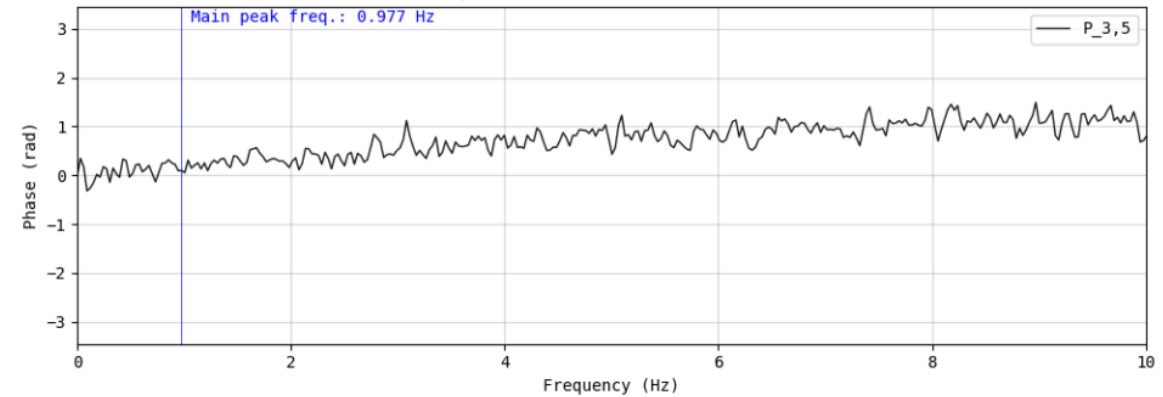
# Improved 1<sup>st</sup> campaign analysis methodology

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Old (top) and new (left) phase angle evaluation between detectors 3 & 5



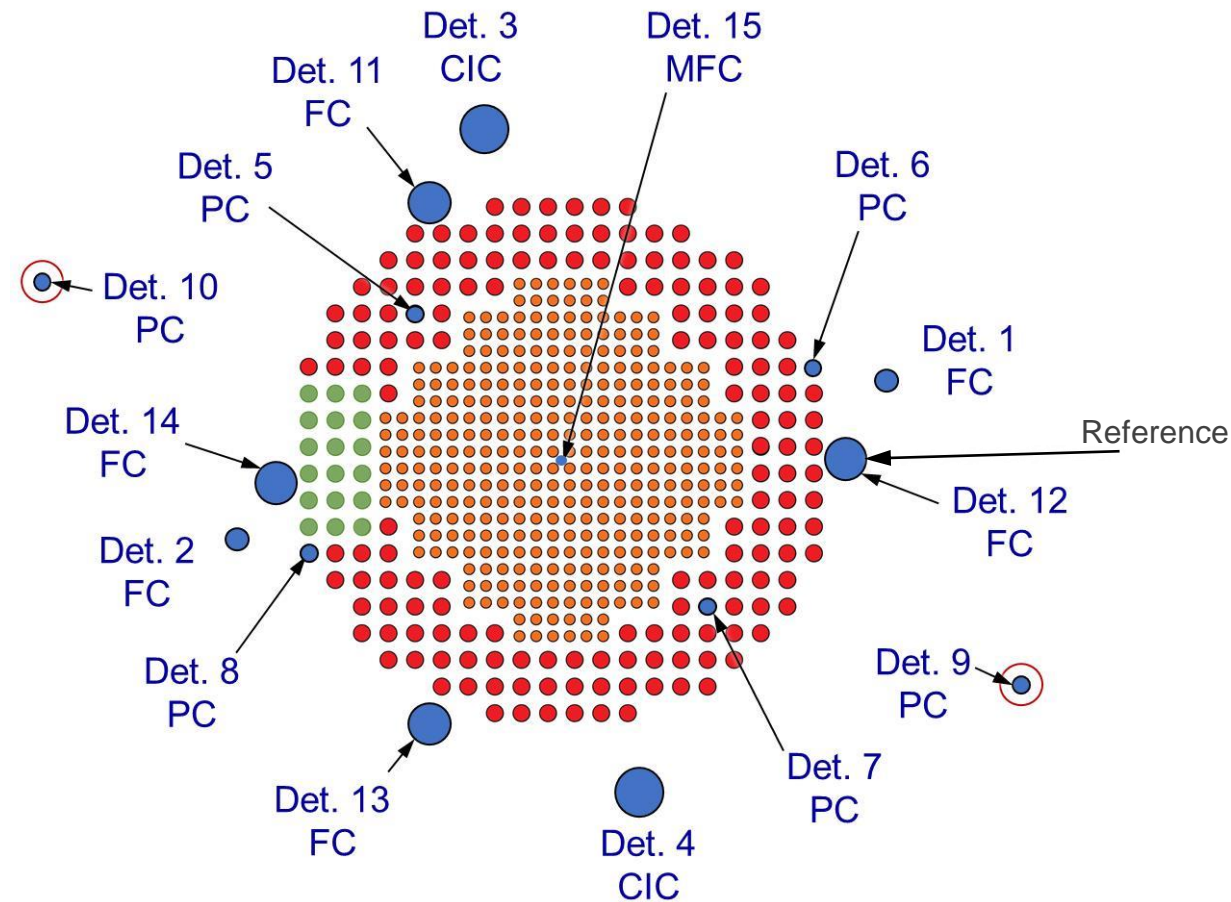
# Preliminary results of 2<sup>nd</sup> campaign

## Improvements:

- More detectors + strategic locations (e.g. behind oscillator)
- Longer measurements (~few 1000 s)
- Repeatability
- Inclusion of correlations & covariances
- Uncertainty propagation

## ...shortcomings

- Repeatability more focused
- Propagated and uncertainty differs from std. of final values.

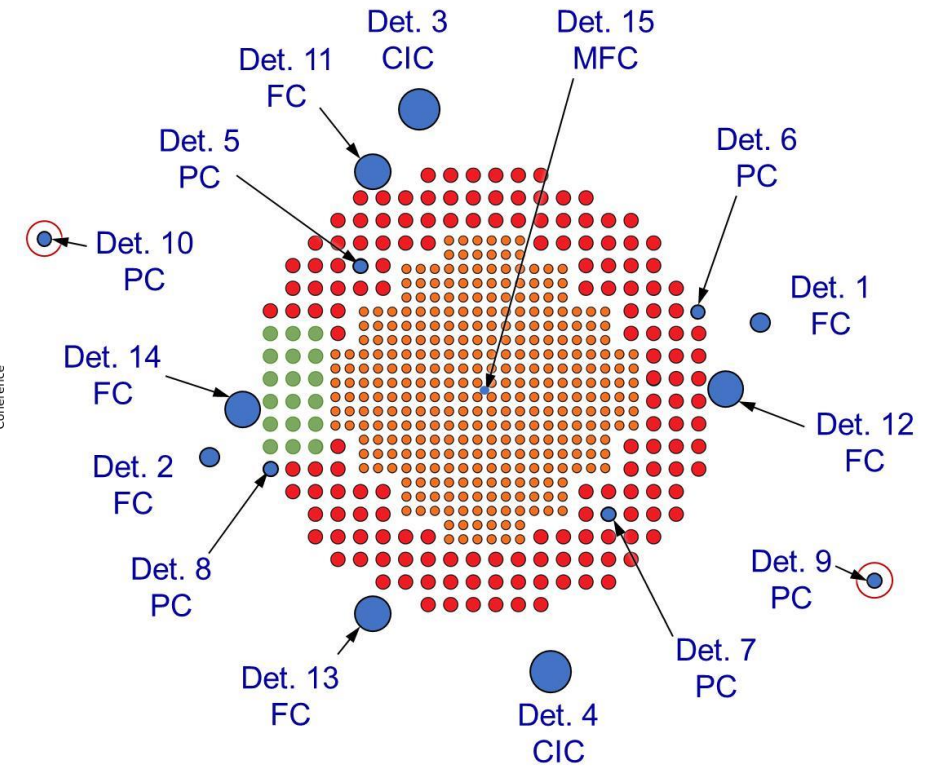
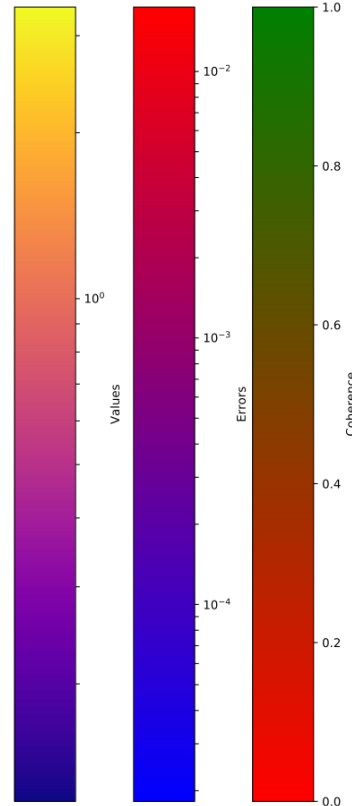




# Preliminary results of 2<sup>nd</sup> campaign

PSD area normalized to det. 12: abs. value @ Base frequency

det 1	1.24e+00	3.37e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.12e+00	4.50e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.24e-01	1.03e+00
det 2	1.17e+00	3.38e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.23e-01	1.02e+00
det 3	1.16e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.22e-01	1.02e+00
det 4	1.16e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.22e-01	1.02e+00
det 5	1.17e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.23e-01	1.02e+00
det 6	1.16e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.22e-01	1.02e+00
det 7	1.17e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.12e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.23e-01	1.02e+00
det 8	1.17e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.52e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.23e-01	1.02e+00
det 9	1.17e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.49e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.23e-01	1.02e+00
det 10	1.16e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.22e-01	1.02e+00
det 11	1.16e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.22e-01	1.02e+00
det 12	1.16e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.05e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.22e-01	1.02e+00
det 13	1.16e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.48e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.22e-01	1.02e+00
det 14	1.18e+00	3.37e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.49e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.26e-01	1.03e+00
det 15	1.18e+00	3.37e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.49e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.23e-01	1.05e+00
Mean	1.17e+00	3.36e+00	1.18e+00	1.08e+00	1.21e+00	1.07e+00	1.11e+00	4.49e-01	1.06e+00	2.72e+00	1.09e+00	1.00e+00	1.15e+00	1.23e-01	1.02e+00
Prop. rel. error	1.16e-03	2.70e-04	1.89e-05	1.82e-05	2.29e-04	8.08e-05	2.68e-04	3.27e-04	3.32e-04	7.01e-05	3.06e-05	5.21e-05	3.24e-05	7.81e-04	6.86e-04
Mean rel. error	1.74e-02	1.83e-03	1.04e-04	1.05e-04	1.44e-03	3.62e-04	1.71e-03	2.24e-03	2.39e-03	2.95e-04	1.18e-04	0.00e+00	1.24e-04	8.05e-03	6.72e-03
	det 1	det 2	det 3	det 4	det 5	det 6	det 7	det 8	det 9	det 10	det 11	det 12	det 13	det 14	det 15



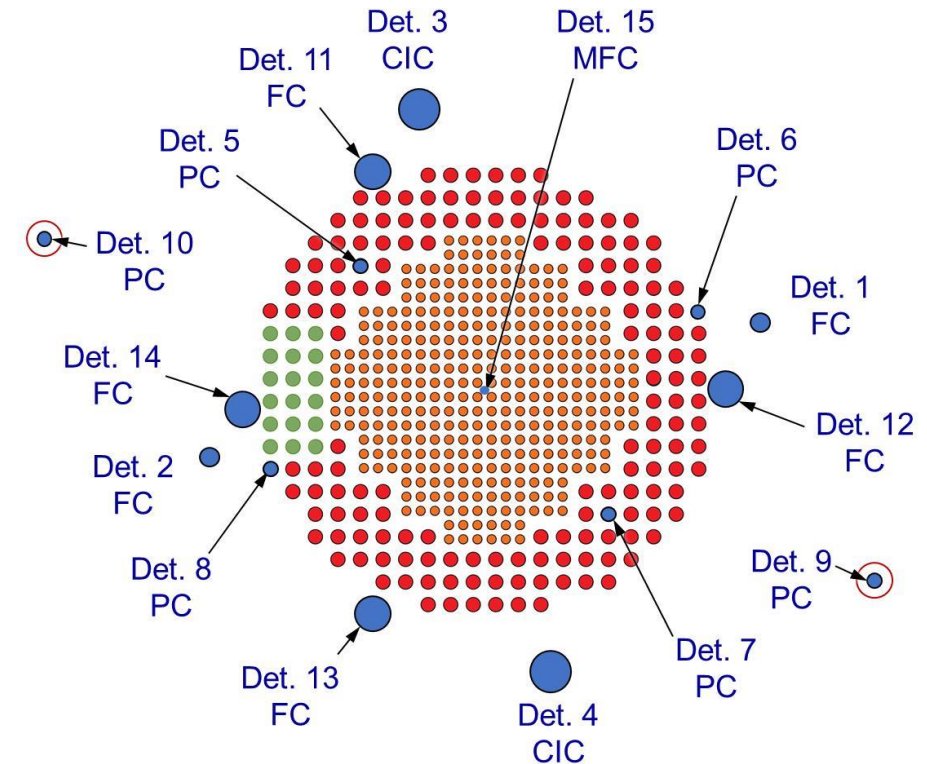
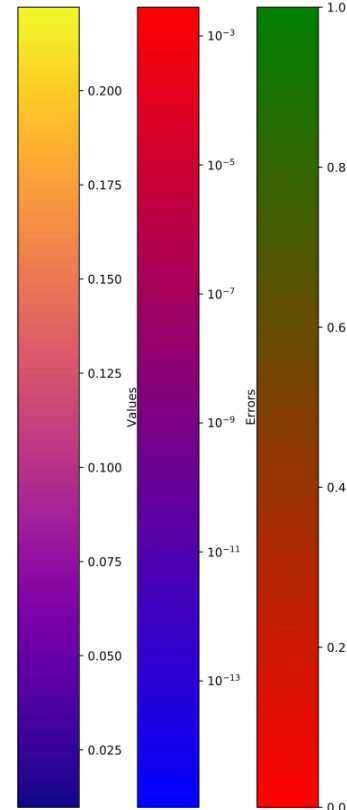
Spectral power (PS) ratio for measurement at 0.97 Hz and oscillation amplitude of 1.5 mm.



# Preliminary results of 2<sup>nd</sup> campaign

Phase angle difference to det. 12: abs. value [rad] @ Base frequency

det 1	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 2	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 3	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 4	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 5	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 6	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 7	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 8	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 9	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 10	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 11	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 12	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 13	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 14	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
det 15	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
Mean	1.01e-01	1.38e-01	9.77e-03	2.16e-02	1.55e-01	1.08e-01	1.38e-01	2.22e-01	6.60e-02	2.06e-01	1.41e-02	0.00e+00	3.47e-02	-1.31e+00	1.75e-01
Prop. error	2.79e-03	8.81e-05	1.82e-05	2.08e-05	1.18e-04	1.97e-05	1.73e-04	2.43e-04	1.19e-04	1.58e-05	2.40e-06	2.13e-06	1.36e-06	1.17e-03	7.10e-04
Mean error	5.09e-15	1.22e-15	2.03e-15	1.28e-15	5.42e-15	5.56e-15	1.47e-15	5.78e-15	1.10e-15	2.84e-15	4.44e-15	0.00e+00	5.49e-15	1.19e-14	1.09e-14
	det 1	det 2	det 3	det 4	det 5	det 6	det 7	det 8	det 9	det 10	det 11	det 12	det 13	det 14	det 15

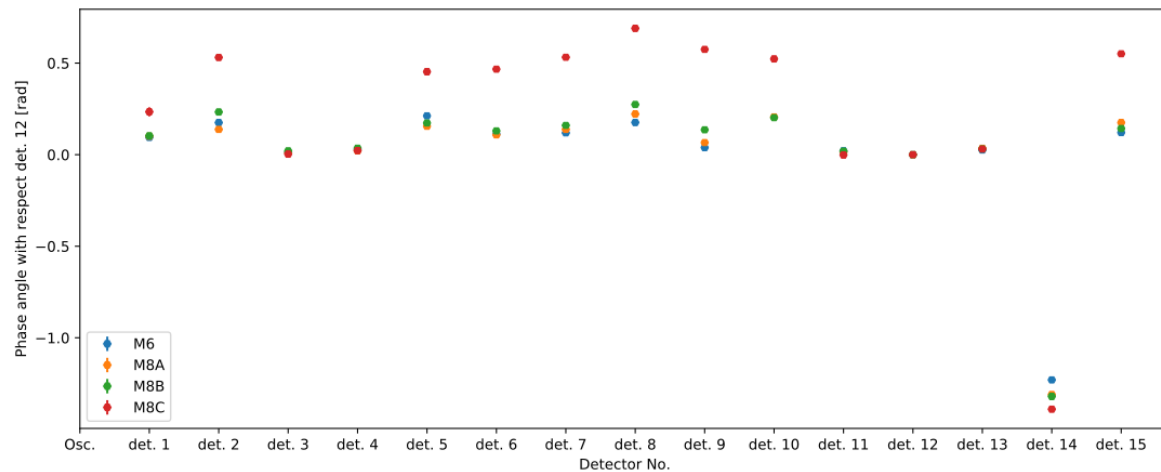
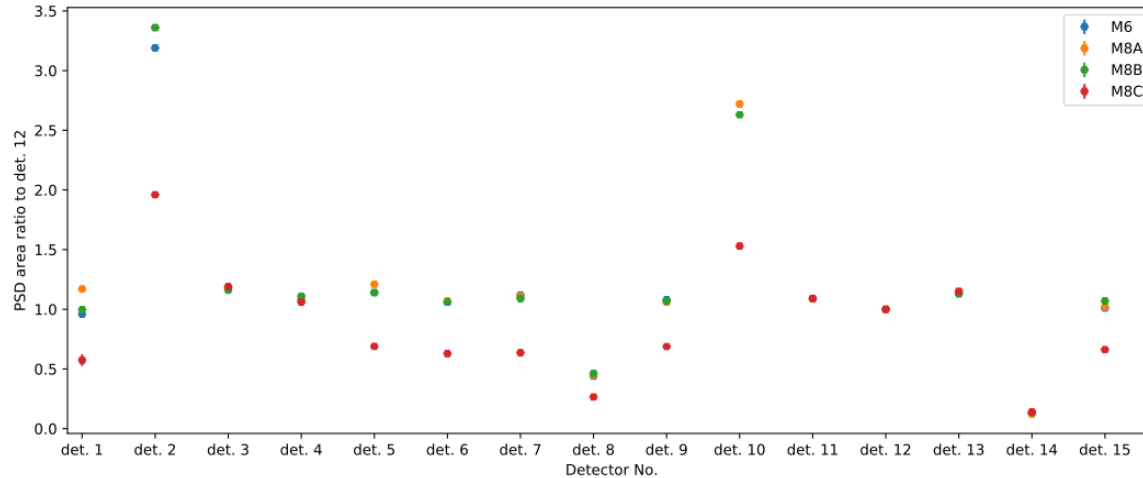


Phase angle difference for measurement at 0.97 Hz and oscillation amplitude of 1.5 mm.

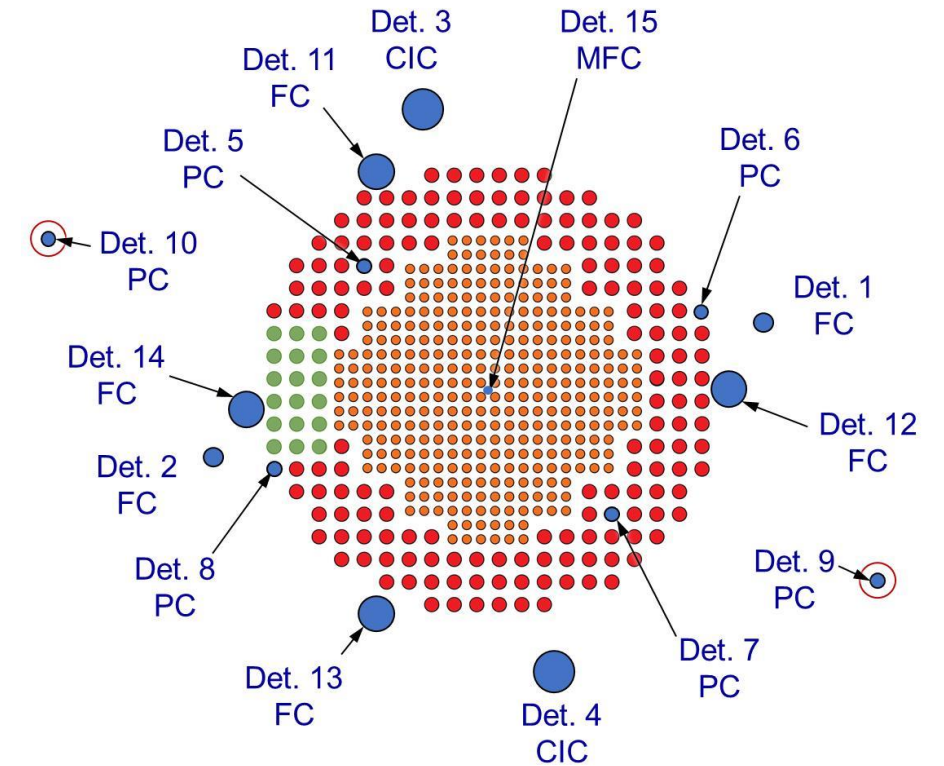


# Preliminary results of 2<sup>nd</sup> campaign

## Consistency: PS ratio



## Consistency: Phase angle difference



Something clearly occurred during measurement M8C!



# 3<sup>rd</sup> campaign

## Improvements:

- 18 detectors in total
- More repeatability
- Neutron current detector
- 2x synchronized oscillators (COLIBRI + POLLEN)
- Taking into account all correlations + all uncertainties we know of

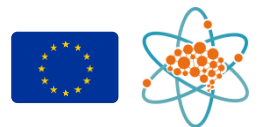
## ...shortcomings

- Analysis in progress



# Lessons learned

- Less data points, but better ones
- If you cannot know, repeat (and vice versa)
  - Importance of repeatability, especially for COLIBRI: imperfect oscillation
  - Importance of maximal data: collection of position signal for full propagation
- Data analysis of noise experiments is quickly tough (and expensive)
- Research reactors can contribute to noise code validation, but high spatial resolution is needed
- Spatial dependence of noise seem to be at hand!



**Thank you!**

