Extending 3D Magnetic Diagnostics on NSTX-U

by

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Acknowledgements

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GENERAL ATOMICS

Conceptual design of new 3D magnetic diagnostics on NSTX-U has been developed as part of GA collaborative research

- **Expanded magnetic sensor set on DIII-D has enabled improved understanding in many areas of 3D physics**
  - Plasma response
  - RMP ELM suppression
  - Error field sensitivity and optimization
  - 3D magnetic field torques

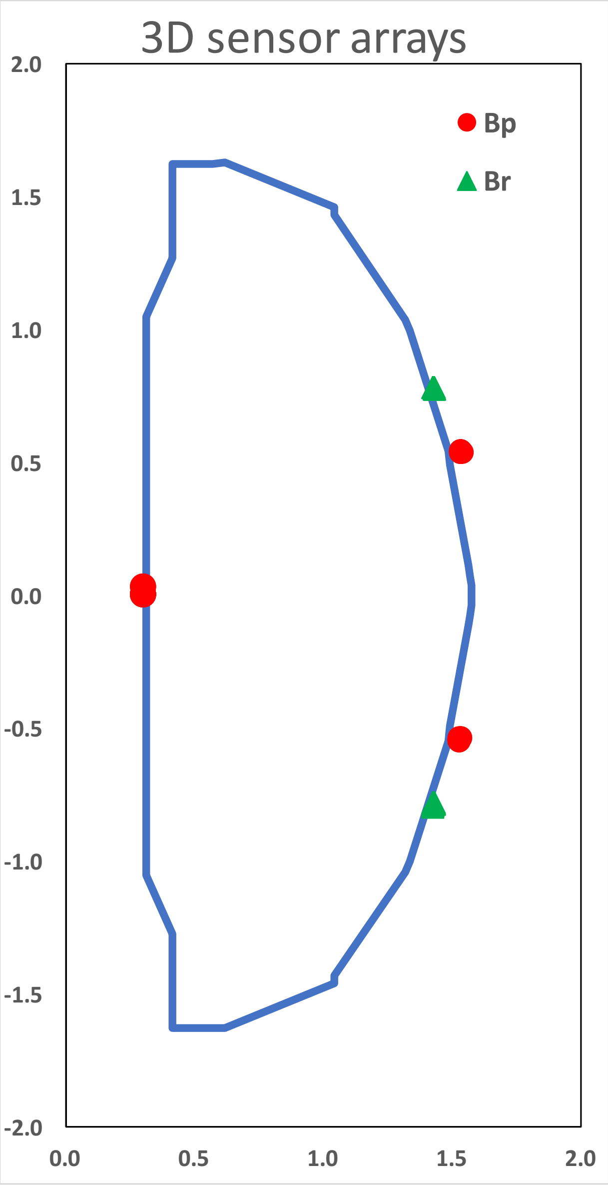
- **GA-NSTXU collaboration leverages experience and tools developed during DIII-D upgrade**

- **Overview of DOE project milestones**
  - M15. Evaluate completeness of existing magnetic diagnostics ✅
  - M16. Report on conceptual design ✅
  - M17. Report on final physics design
  - M18. Report on frequency response and noise evaluation of new sensors
  - M19. Report on new experimental results with model comparisons

Milestone 15: How NSTX-U 3D magnetic diagnostics can be improved

- **Five 3D B field arrays exist on NSTX-U**
  - Two 12-sensor B_r & B_p arrays on LFS above and below the midplane (from NSTX)
  - One 10-sensor poloidal field array on HFS midplane (new, not yet instrumented)

- **Existing sensors were evaluated in terms of ability to resolve toroidal and poloidal structure of slowly-rotating and DC magnetic fields**
  - Toroidal distribution of sensors in existing arrays sufficient for n<=3 on LFS and HFS
  - Poloidal distribution of sensor arrays insufficient to resolve poloidal structure



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Milestone 16: outline

- **Poloidal location of toroidal arrays**
  - MARS-K simulations
  - B_p signal strength and poloidal wavelength
  - B_r component
- **Instrumentation of the arrays**
  - Condition number to evaluate pairing scheme
  - LFS arrays
  - HFS arrays
  - Lower cost alternative
- **Summary and next step**

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MHD simulations of plasma response to NCC fields

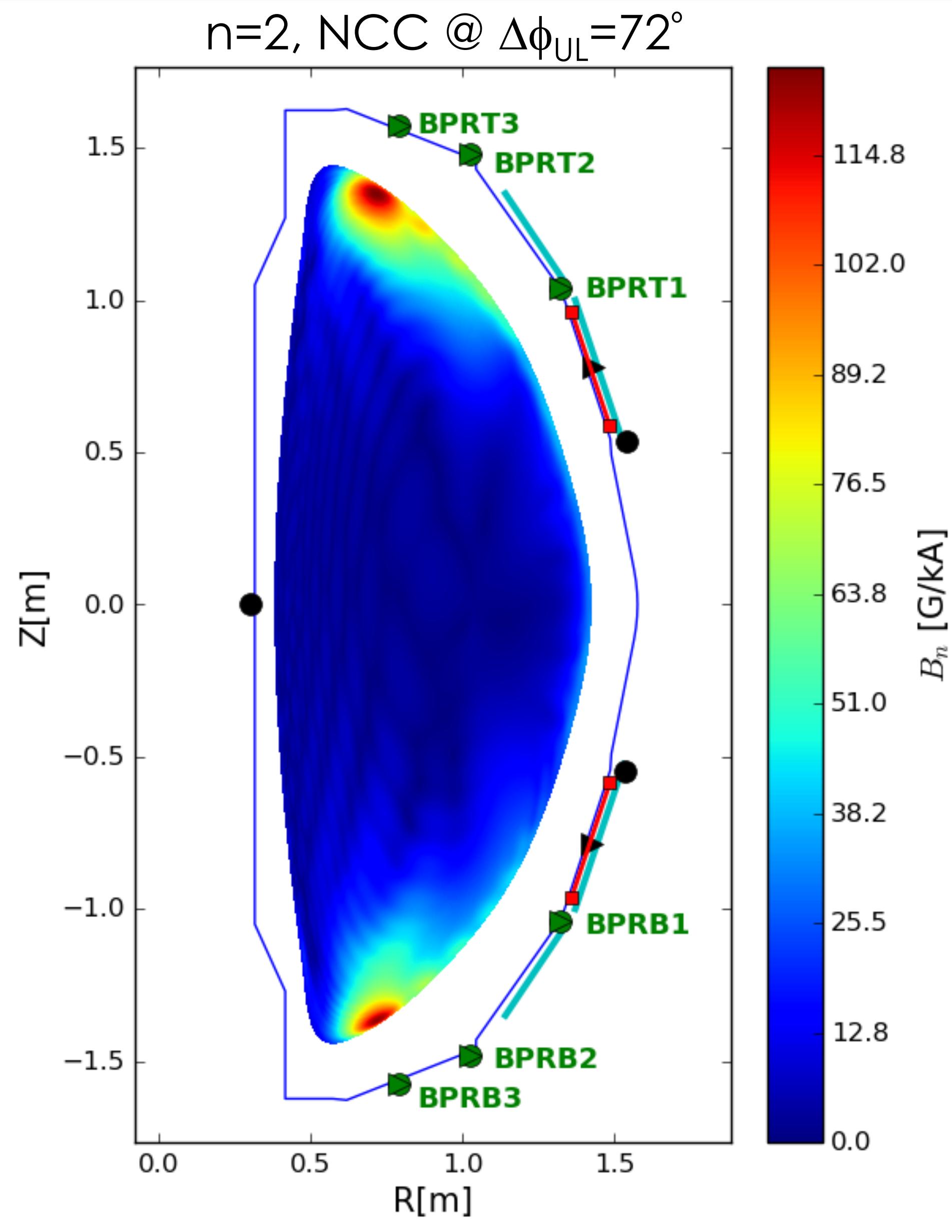
Study done using MARS-K for 2 different equilibria:
β_N~2.5 and β_N~5.5

Mode analyzed: n=1,2 and 3

NCC coil energized in separate simulations and combined at several phases.

The passive plates are not considered in the simulations (DC field simulated)

Signal measured by the existing B_p (●) and B_r (▶) probe as well as for the suggested new arrays are analyzed



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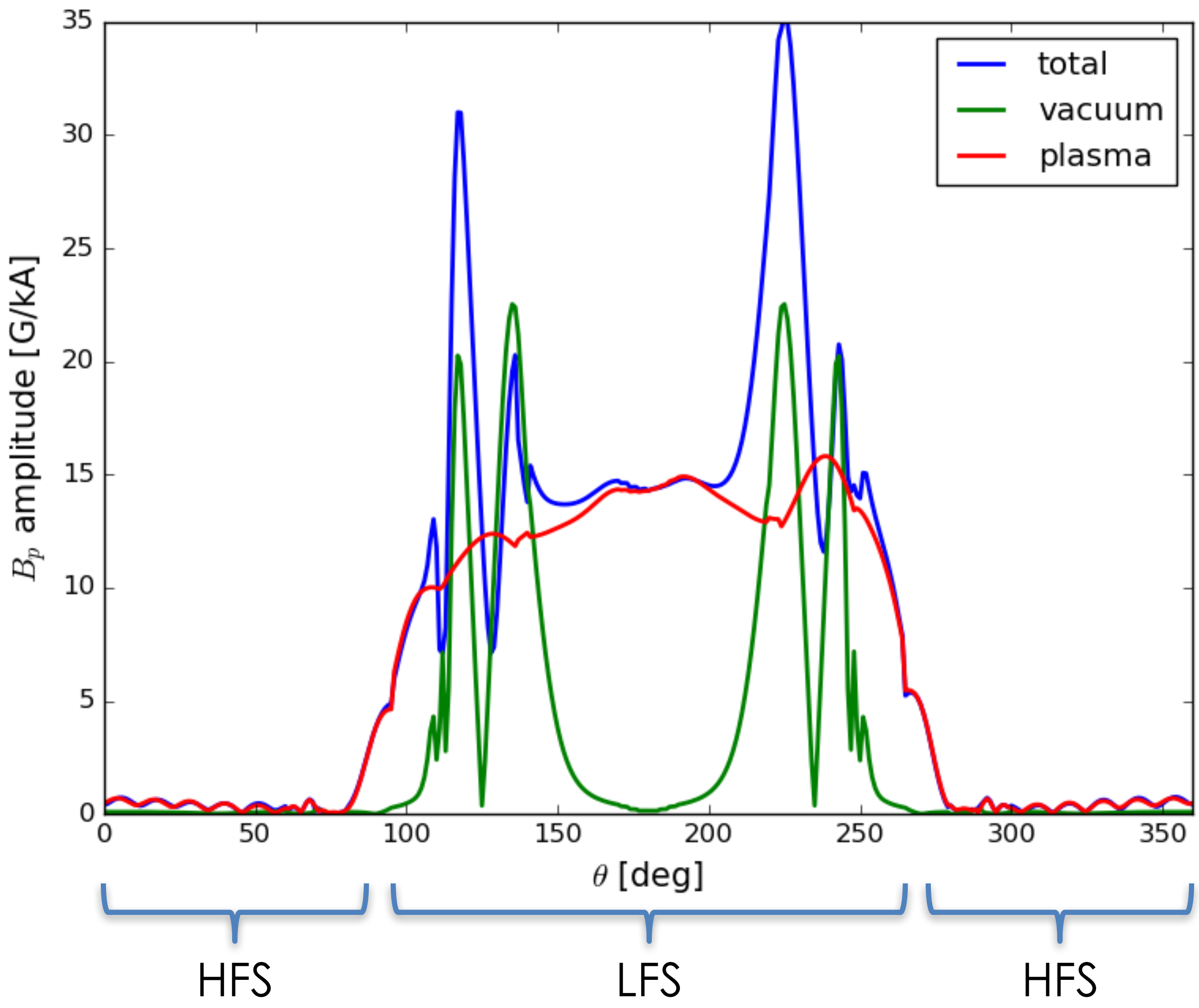
Looking at the signal at the wall due to the plasma

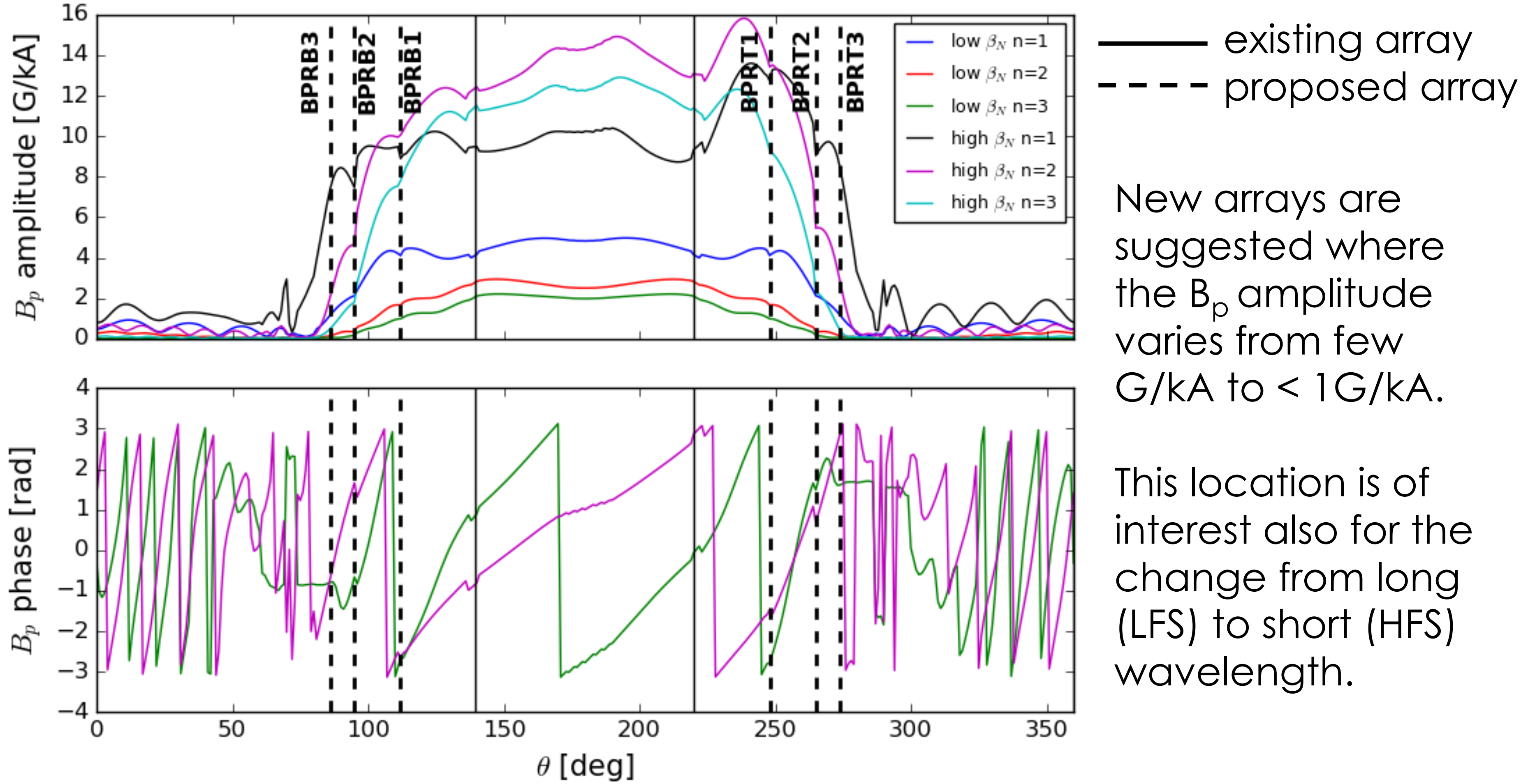
2 MARS-K simulations, one considering the presence of the plasma (total) and one in vacuum.

The latter is subtracted to the former to obtain the field at the wall due only to the plasma response.

This quantity is what will been considered from now on.



Top and bottom are the most interesting positions to add new B_p arrays



New arrays are suggested where the B_p amplitude varies from few G/kA to < 1G/kA.

This location is of interest also for the change from long (LFS) to short (HFS) wavelength.

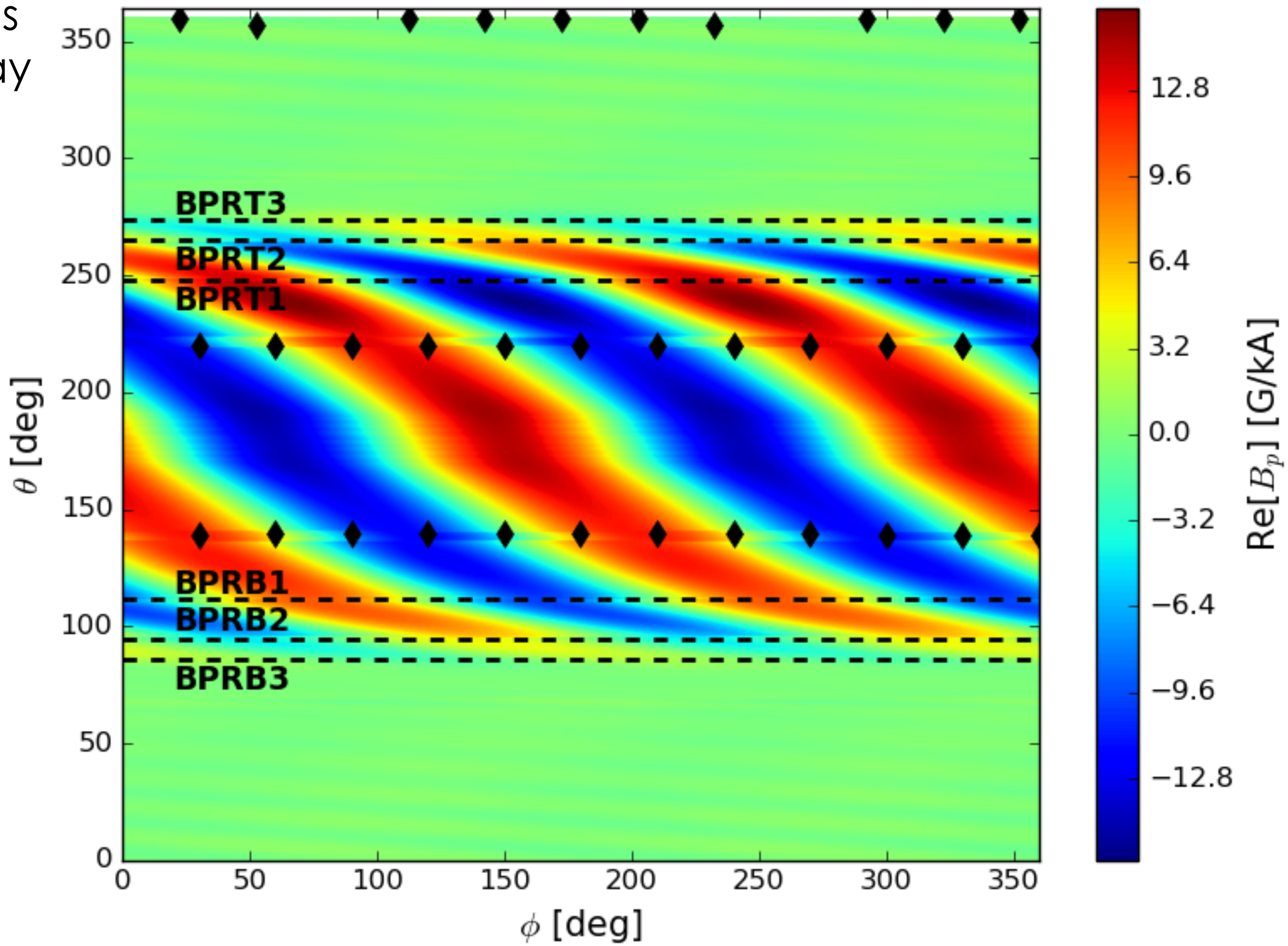
Projection of B_p on the wall

◆ existing probes
- - - proposed array

n=2 case for β_N~5.5

The suggested arrays are in the location were the wavelength is changing.

Their separation is smaller than the wavelength also for n=3, preventing aliasing



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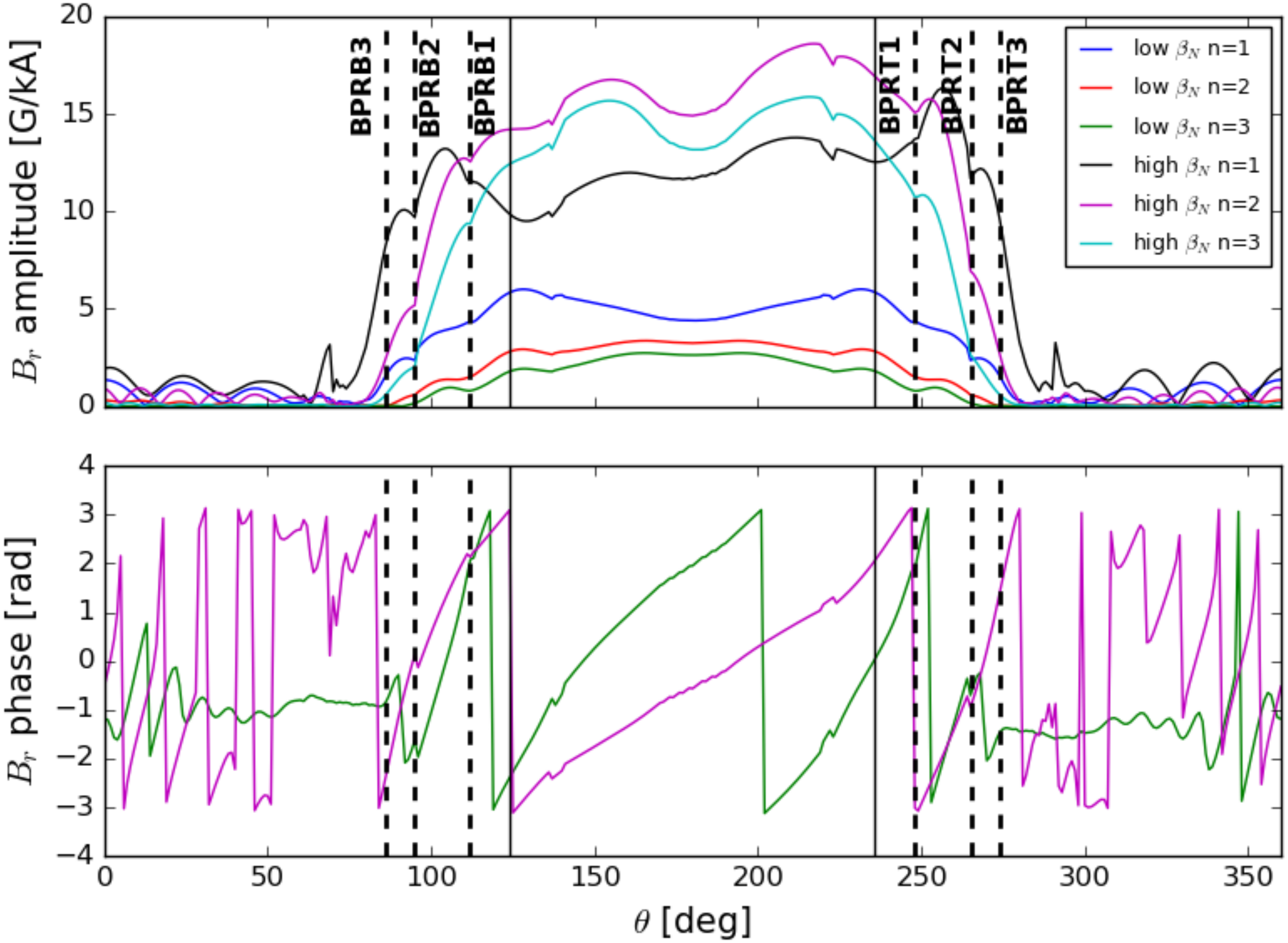
B_r has a behavior similar to B_p



existing array
proposed array

Good positions for the Br arrays are similar to the B_p ones.

The positions chosen considered also hardware limitations, such as:

- limited space in the HFS and LFS midplane
- presence of passive plates

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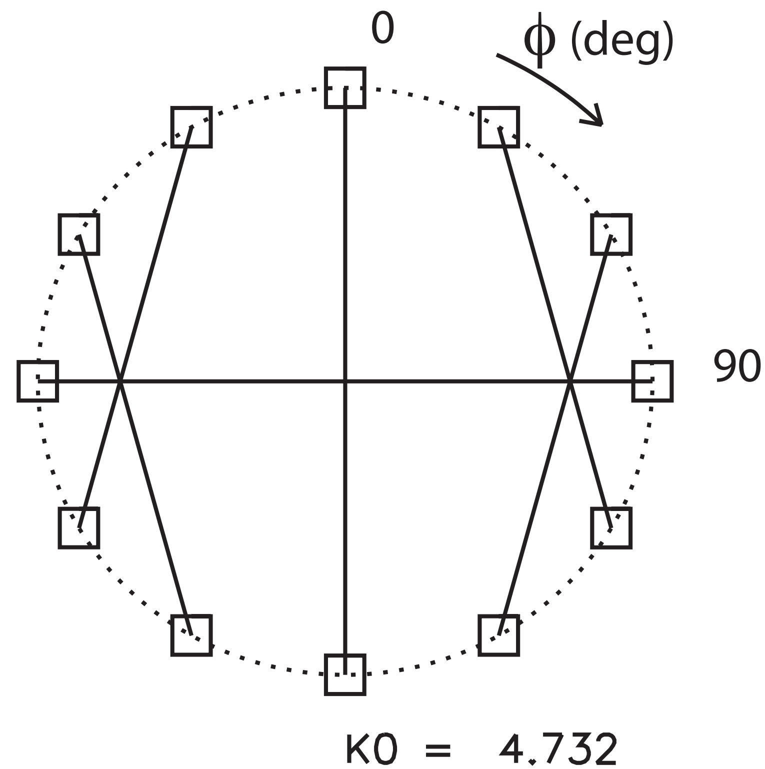
Reconfiguring the pairs connections will make the best use of the existing arrays

- **Actual LFS configuration**:
  - 12 probes
  - 6 pairs acquired as sum and difference

- **Considerations**:
  - Sum has interesting information but likely very noisy and uncertain
  - Difference eliminate n=0 part, improved signal/noise
  - Condition number of the basis matrix used to evaluate the pairing scheme



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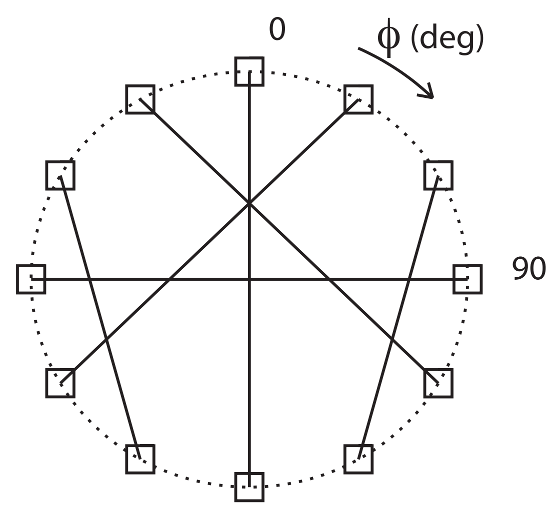
Condition number of the basis matrix used to evaluate the pairing scheme

- When we fit the data we want to solve $A \cdot x = b$ where A is the basis matrix, b the measurements and x the fitting parameters.

- A contains a mix of info about the data available and the desired fit.

- $A = USV^T$ with S diagonal. $\mathrm{K(A)} = max(s_i)\,/\min(s_i)$ is the conditioning number and is used as figure of merit to evaluate how well the data constrain the fit. The best is $K = 1$

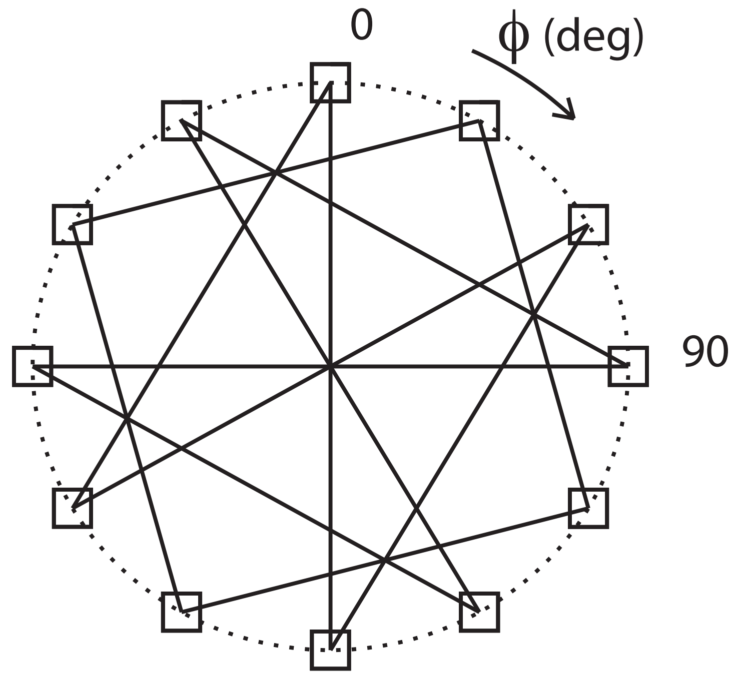
- **Simplest improvement:**
  - Pairs tested to fit n=1,2,3
  - Actual $K = 4.732$
  - Interchanging 2 pair connection improves significantly the system capability



New suggested configuration for the LFS arrays

Possible new configuration to measure n=1,2,3:

- Same number of probes, but now 12 pairs
- Each probe is part of 2 different pairs
- The system is resilient to the loss of a probe



K0 = 1.225
K1 = 2.297

Worst conditioning number if a probe is lost

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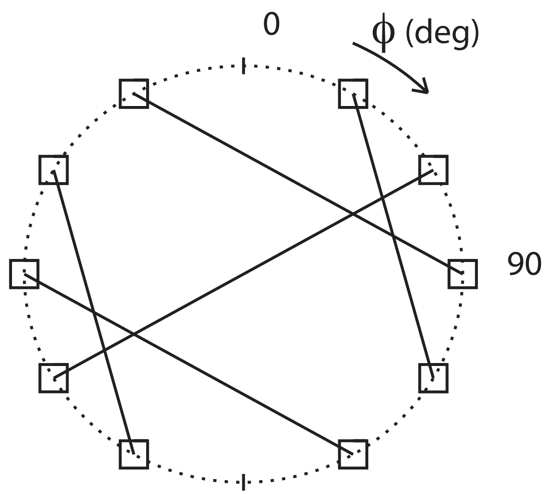
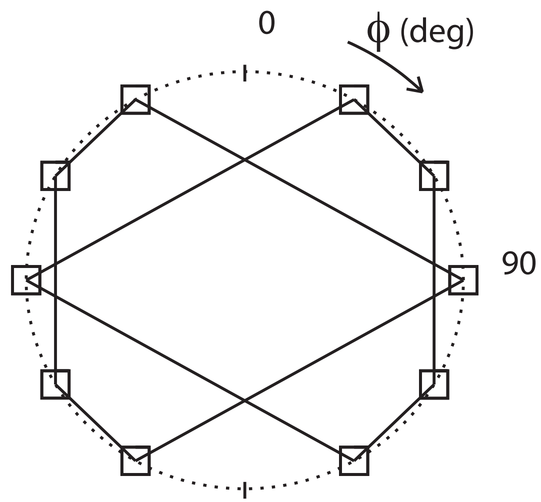
Suggested configurations for the HFS array



K0 = 1.345
K1 = 2.648



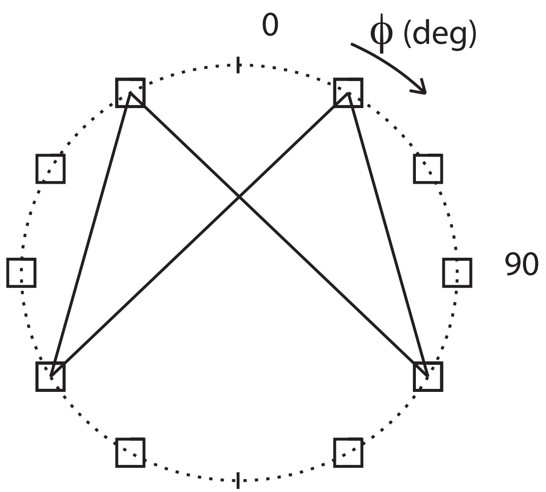
K0 = 1.891
K1 = 3.321

- It follows the actual LFS configuration.
- 5 pairs.
- Only n=1,2 can be detected.

- 10 pairs.
- n=1,2,3 can be detected.

Lower cost alternative

- Method suggested as alternative for the proposed new arrays and for initial instrumentation of the HFS.
- Suitable only when a single n mode is dominant.
- n=1 or n=2 or n=3 can be detected using 4 pairs.



K(1) = 1.366
K(2) = 1.225
K(3) = 1.000

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Recommendations

- 6 new poloidal locations have been identified as recommended to improve the poloidal resolution, both for B_p and B_r sensors.
- A different connection scheme is recommended for the existing set of probes following the condition number method.
- Instrumentation of the HFS array is recommended. The probes are already installed, it just needs integrators and some channels on a digitizer.

Next step: physics design

Possible next steps may include:

- Assess impact of the passive plates on the proposed new sensors
- Evaluate requirements for the full capabilities of the NCC coils ($n \le 6$)
- Identify space constraints on new sensors
- Explore concepts for compact magnetic sensors
- …

Milestone 17 (final design) is due on 02/28/2018

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