Gas Puff Imaging Diagnostic on NSTX-U

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NSTX-U

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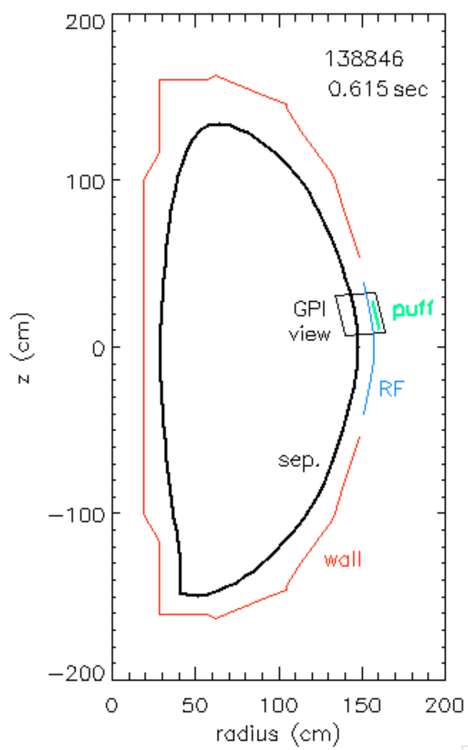
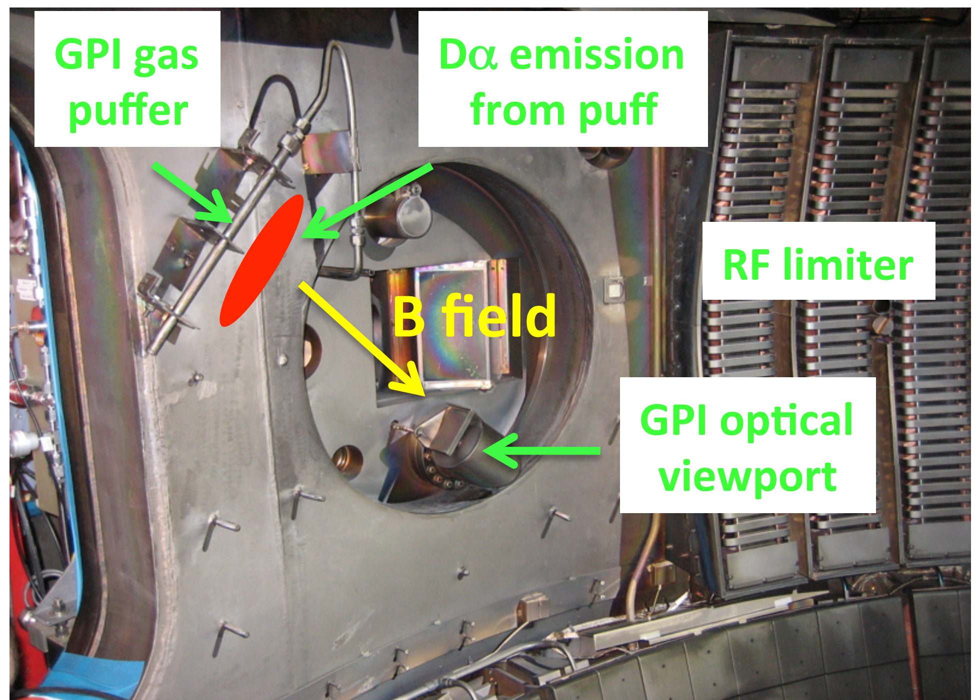
Abstract

The first results and plans for the gas puff imaging (GPI) diagnostic on NSTX-U will be described. The GPI optical efficiency has been improved by about x10 using a new fiber bundle and interference filter, and the new optics has a zoom lens which can potentially resolve turbulence below the ion-gyroradius scale. Experiments are planned to study high-k edge turbulence, correlations of edge turbulence with the SOL heat flux width, and the trigger mechanism of the L-H transition. A second fast camera is planned to view the GPI gas cloud from across the machine, which can potentially measure the field line pitch by simultaneously viewing individual field-aligned blob filaments in the radial vs. poloidal (GPI) and toroidal vs. poloidal (second camera) directions. An incoming collaboration from MIT will bring a 9x10 pixel APD-based detector array from Alcator C-Mod to NSTX-U, initially for faster and more sensitive imaging of the existing GPI gas puff. New results and further diagnostic plans will be described.

Gas Puff Imaging (GPI) Diagnostic on NSTX

- D_2 gas puffed from GPI manifold on outer wall above midplane
- Dα light emission from gas puff viewed from along local B field
- Fluctuations in Dα light emission interpreted as edge turbulence

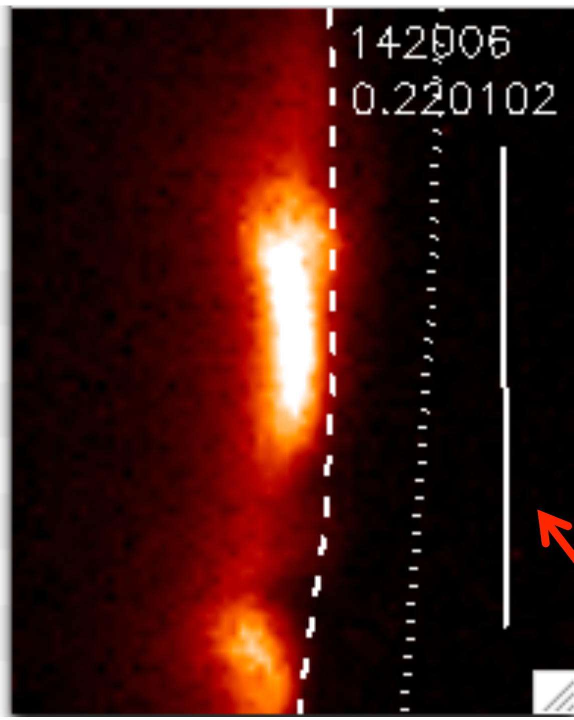




Typical GPI Images from NSTX (2010 data)

- Exposure time/frame = 2.1 μsec/frame @ 400,000 frames/sec

L-mode



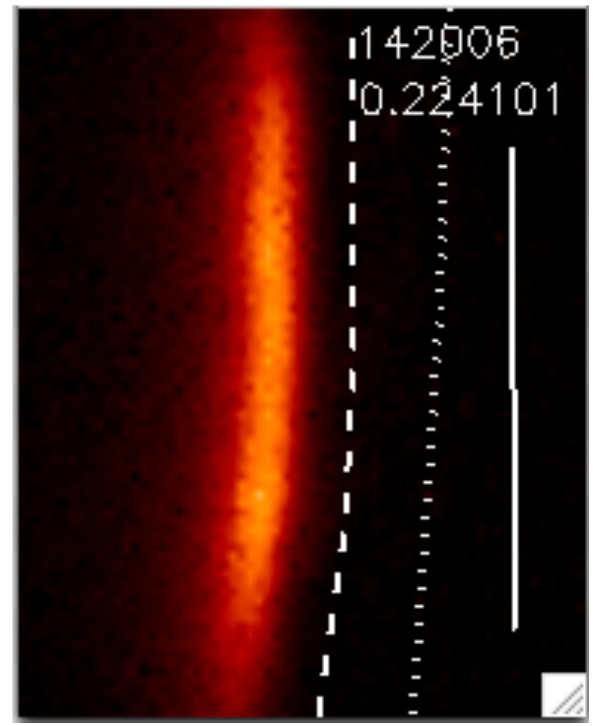
GPI gas injector

separatrix

RF antenna shadow

poloidal
80 pixels
30 cm

H-mode



radial
64 pixels
24 cm

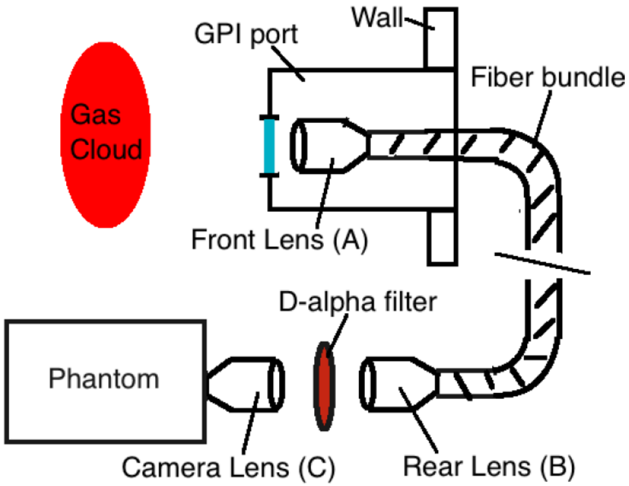
GPI Optics Improvements for NSTX-U

These upgrades were implemented for the 2016 run:

- New Schott coherent fiber bundle, 8x10 mm and 9 ft. long (improves signal x4 due to browning of prior bundle)
- New Dα interference filter with wider bandwidth 9 nm FWHM (~80% transmission vs. prior ~35%)
- New optical zoom lenses to improve GPI spatial resolution (manual zoom from ~0.5 cm to ~0.1 cm at gas cloud)

=> ~10x larger GPI signal should allow reduced GPI gas puff rate and better space and/or time resolution

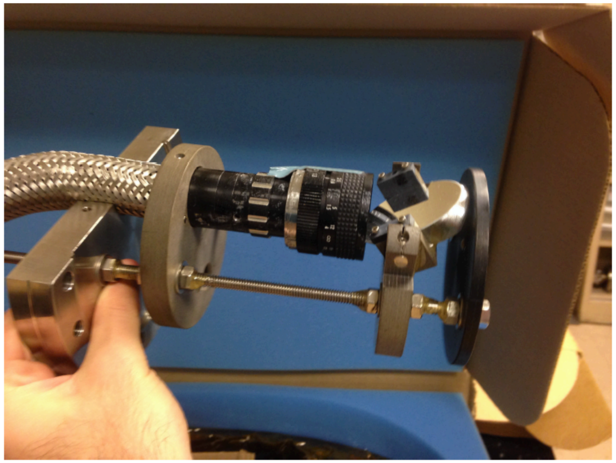
Zoom Lens for Improved Spatial Resolution



Front lens changed from 25 mm to 8-48 mm zoom

Camera lens changed from 25 mm to 8-48 mm zoom

2010 front end lens



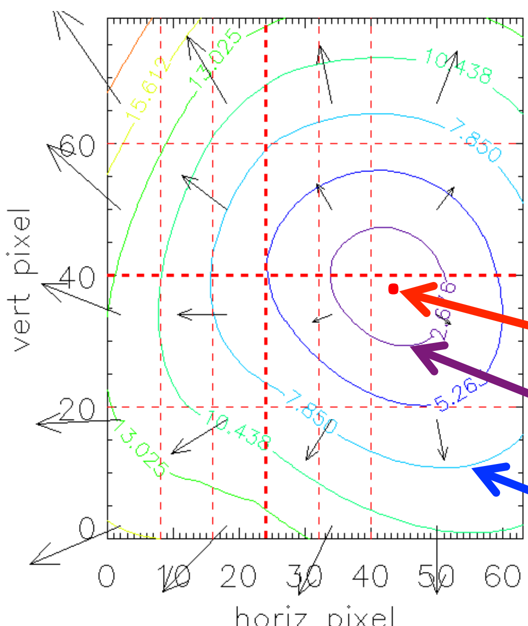
2016 front end lens

Limitation due to B Field Angle Alignment

- Maximum GPI optical zoom has ~ 1 mm spatial resolution
- Could resolve structure $k_{pol}\,\rho_i$ ~ 1 at edge (T_i=100 eV, B=1 T)
- But misalignment of GPI view with B can "smear" resolution

Arrows are misalignment angles to the local B field

24x30 cm GPI field of view



139501
0.515 sec

smearing due to parallel length of GPI cloud: Δ_{smear} ~ $L_{II,cloud}$ tan θ_B

e.g. for θ ~ 1º, $L_{II,cloud}$ ~ 15 cm, Δ_{smear} ~ 0.3 cm

θ_B ~ 0º perfect alignment (no smearing)

θ_B ~ 2.7º slight misalignment (0.7 cm smearing)

θ_B ~ 8º large misalignment (2.0 cm smearing)

Present GPI Configuration for 2016 Run

- Started with same GPI view as NSTX but with improved optics
- No gas puff available in 2016 run due to engineering delays
- Used Dα filter to view background edge light at 100 kHz
- Zoom lens had vigneting in 24x30 cm view (as expected)

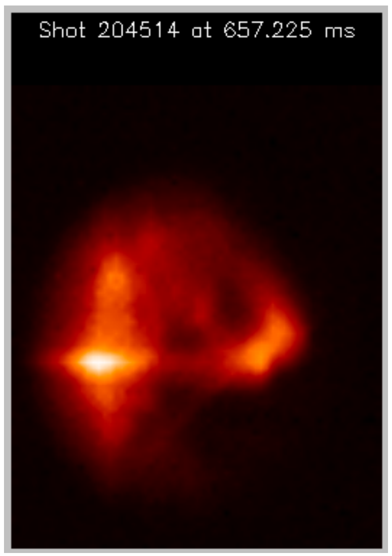
⇒ good data on edge turbulence in background Dα light for whole duration of ~ 100 shots (but with no GPI puff)

⇒ good data on radial Dα profile for edge neutral density measurement (for comparison with ENDD)

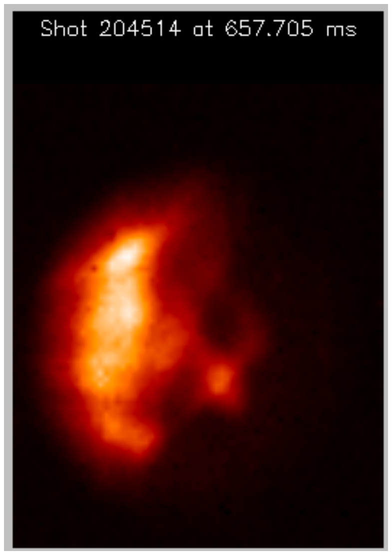
Present GPI Results from 2016 Run

- Edge turbulence in background Dα looked about as expected
  - large fluctuation levels at ~5 cm scale length in L-mode
  - quiet band of Dα emission during H-mode periods

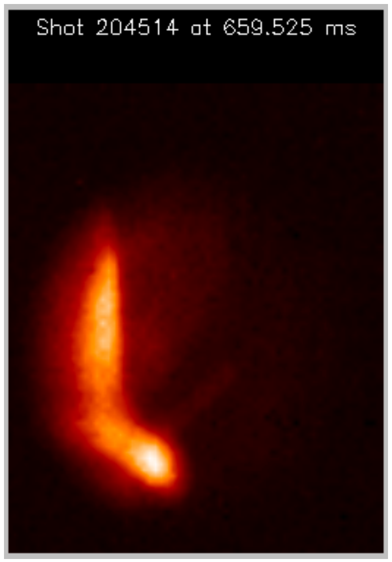
- But difficult to analyze due to lack of GPI spatial localization



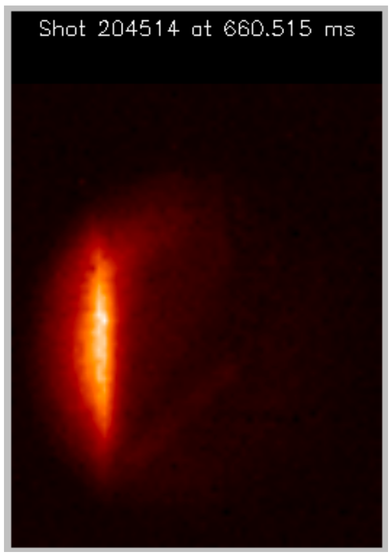
L-mode



L-mode



L-mode



H-mode

Planned and Possible GPI Upgrades

Planned

- APD array from C-Mod to improve signal/noise and bandwidth
- Second Phantom 710 camera to view GPI cloud from the side
- Helium line ratio measurement of edge T_e and n_e profiles

Possible

- Additional GPI view(s) for measuring 3-D filament structure
- Better collimated gas manifold for higher spatial resolution
- Remote control of GPI pan/zoom for small-scale structure

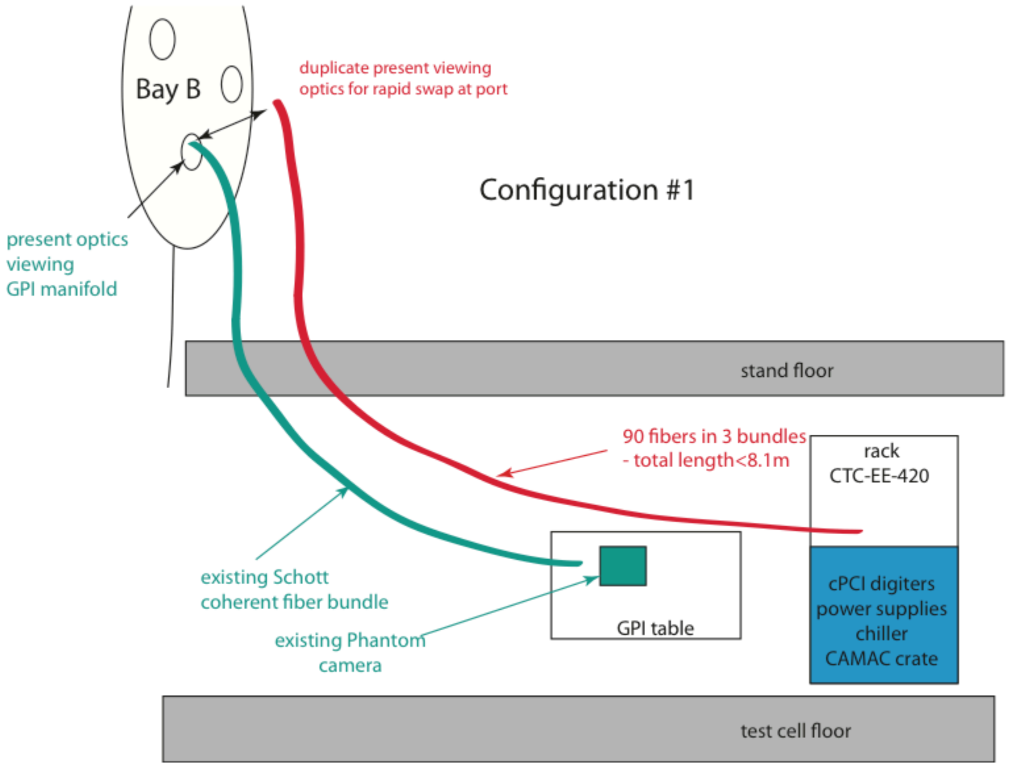
Incoming GPI Collaboration from MIT

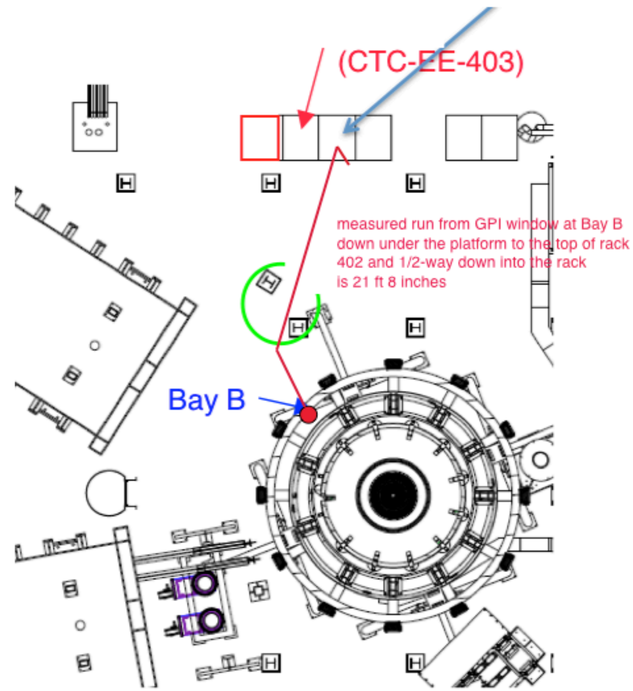
- We plan to install an APD-based GPI system to augment the existing fast-camera-based GPI on NSTX-U
- We will provide operational support for GPI in general

	APD-based detection	**Camera-based using Phantom 7.10**
Spatial resolution	9x10 pixels	64x64 pixels
Time resolution	$f_{Nyquist}$= 1 MHz	$f_{Nyquist}$=0.19 MHz
Sensitivity	optimal	lower signal-to-noise than APDs for same spot size
	Much more sensitive, with excellent time resolution, but poorer image quality	Excellent spatial resolution; best for visualizing the turbulent structures and their evolution

Configuration of MIT APD Array for GPI

Configuration 1 – Easy & rapid swapping of input optics at Bay B



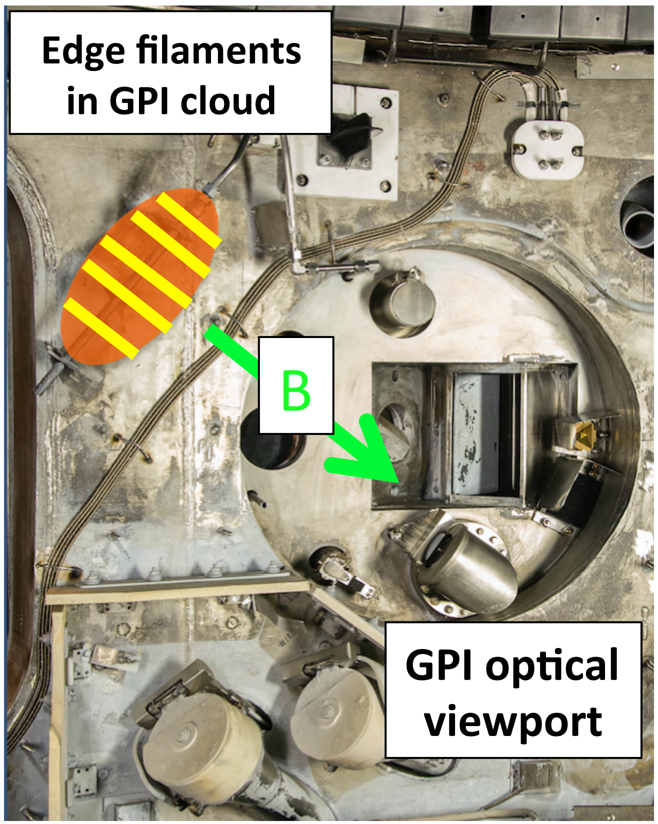


Floor of test cell

Configuration 2 – use beam-splitter on GPI table to direct image to both systems

Planned Side View of GPI Gas Puff Cloud

Using the Phantom 710 camera previously used for GPI at C-Mod



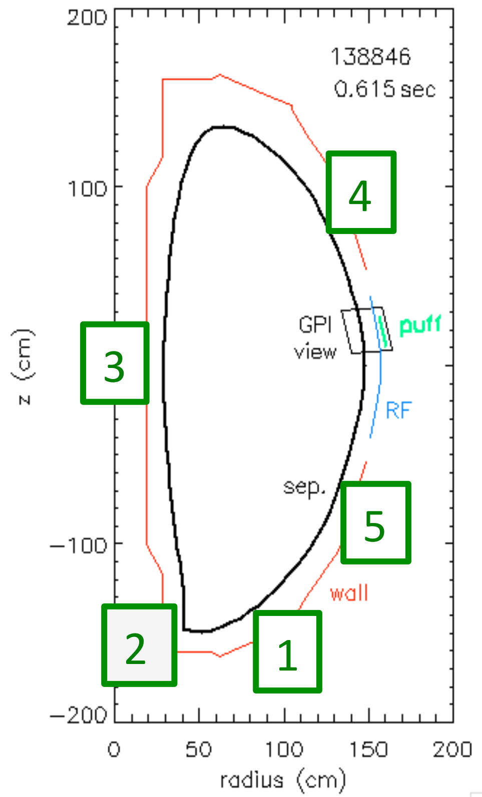
- Compare cloud shape with DEGAS 2
- Correlate filaments with GPI images
- Find local B field line angle => q(r) assuming filaments aligned with B
- Add another gas puffer in field of view to check B-field alignment

Planned Helium Line Ratio Measurement

- The GPI view can be used to measure neutral helium line ratios to determine radial profiles of T_e and n_e in edge (proposed by RFX-mod/Padova and Wisconsin)
- Initial evaluation of expected helium line signals looks good for measurements at > 1 kHz (Burgos et al, Phys. Plasmas 2016)
- These profiles will be useful for the interpretation of GPI signals, and increasing frequency range up to ~100 kHz may be possible with large helium gas puffs (Agostini et al, RSI 2015)
- Main issues are possible perturbation effect of helium gas puff, and self-absorption of helium lines in a large gas puff

Possible Additional GPI Views

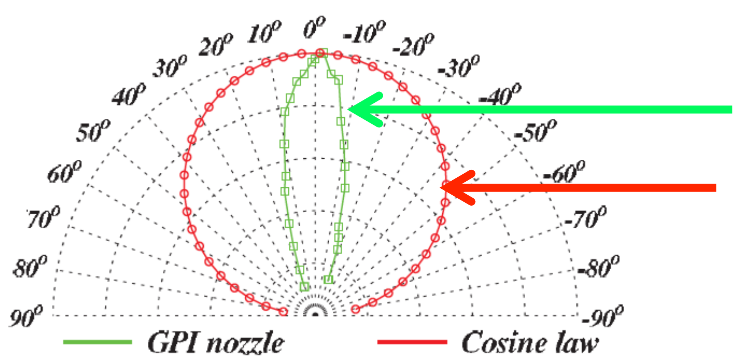
- Needed to evaluate parallel structure/dynamics of turbulence
- Each new view will need a new gas puffer a new fast camera



1) divertor plate surface
2) X-point region
3) inner wall
4) ~ 2 m along B from GPI
5) ~ 5 m along B from (4)

Possible Improvement to Gas Manifold

- Present GPI gas manifold has holes 1 mm diam. x 1 mm deep, which should emit gas with a wide ~ cosine dependence
- TEXTOR GPI manifold has holes 0.5 mm diam. x 15 mm deep, which emits gas with ~20º FWHM angular dependence
- New manifold could significantly improve spatial resolution of GPI, due to shorted parallel length along cloud (see p. 7)



TEXTOR manifold (measured)

NSTX manifold (estimated)

(Shesterikov et al, RSI 2013)

Remote Control of GPI Zoom and Pan

- Present GPI zoom must be adjusted by hand in test cell, and the front-end optics removed to adjust the tilt angle (pan)
- This makes alignment with local B field for measuring small-scale turbulence structure very difficult (can try to adjust plasma to match pre-set zoom and pan)
- Zoom lenses and front-end mirror could be remotely controlled between shots for more efficient measurements
- Main issues are exposure of stepper motors to magnetic fields (air motors ?), and accuracy/reproducibility of the settings

Planned GPI Experiments on NSTX-U

=> these can be done with existing GPI hardware:

- Search for small-scale edge turbulence structure at $k_{pol}\rho_i \sim 1$ (w/Ren, Guttenfelder)
- Correlation of edge turbulence with heat flux SOL width and XGC-1 results (w/ Gray, Chang)
- Continue study of L-H transition (w/Stoltfus-Dueck)
- Continue correlation of GPI with divertor plate turbulence (w/Soukhanovskii)

Planned GPI Studies on NSTX-U

=> these require upgraded GPI hardware:

- Measure turbulence up to ~ 1 MHz with APDs
- Measure turbulence far inside separatrix with APDs
- Measure edge q(r) from GPI + side view filaments
- Compare GPI gas cloud side view with DEGAS 2
- Measure edge T_e and n_e profiles with helium line ratios

also:

- Continue study of blobs, GAMs, zonal flows
- Search for RF-SOL interaction dynamics
- Search for effects of application of 3-D fields
- Study effects of divertor geometry and detachment
- Study coherent edge modes (QCM, EHO, KBM, etc)

Please ask Filippo Scotti (next poster) for further information, or sign up for a copy of this poster: