Collaborator Activities Report

Control of Neutral Fueling and Helium Exhaust to NSTX-Upgrade Plasmas by Three-Dimensional Magnetic Control Fields

DoE grant DE-SC00012315

Oliver Schmitz

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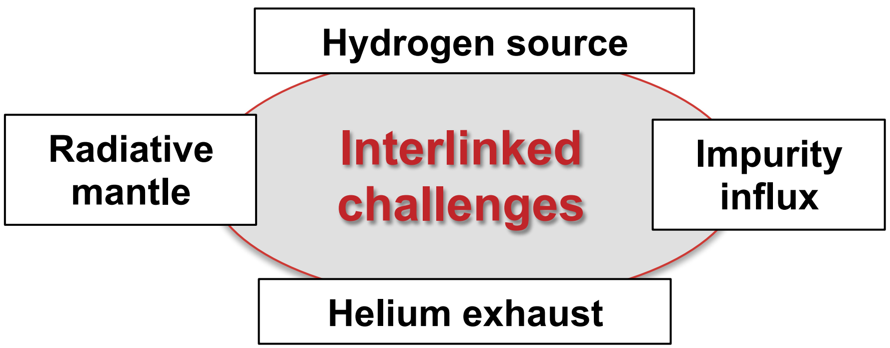
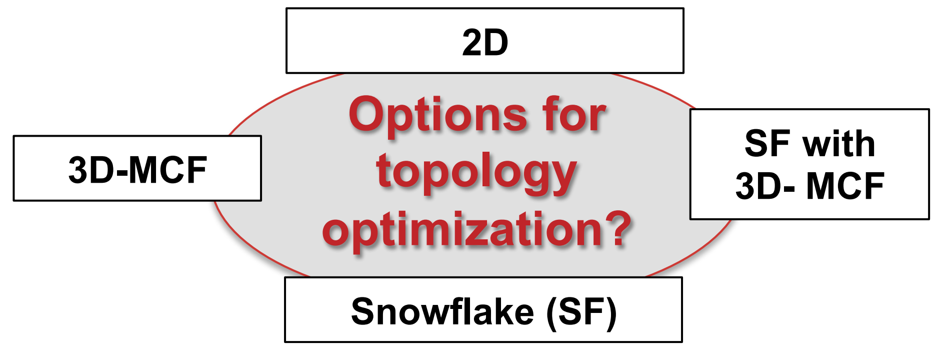
Department of Engineering Physics, Madison, WI, USA

Participants – all positions are filled
- Heinke Frerichs, Numerical Scientist
- Kurt Flesch, PhD student (experiment), behind Qual, soon 100% research
- Ian Waters, PhD student (numerical), behind Qual, soon 100% research

The research scheme in a nutshell

Focus: **enhanced discharge duration in NSTX-Upgrade requires governance of neutral exhaust and fueling including heat exhaust by radiation**





Goal: **Explore topology optimization for improved neutral fueling and exhaust control to generate stable, high density conditions in NSTX-U**

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Interlinked challenges

- Hydrogen source
- Radiative mantle
- Impurity influx
- Helium exhaust

Options for topology optimization?

- 2D
- 3D-MCF
- SF with 3D- MCF
- Snowflake (SF)

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Method I: Reliable experimental approaches

- He line ratio spectroscopy
- Penning gauge spectroscopy

Method II: State of the art 3D MHD and edge & neutral transport modeling

EMC3-Eirene ⟷ NIMROD

Predictive capability: development and validation of combined EMC3-Eirene and NIMROD code package

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PhD K. Flesch

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H. Frerichs

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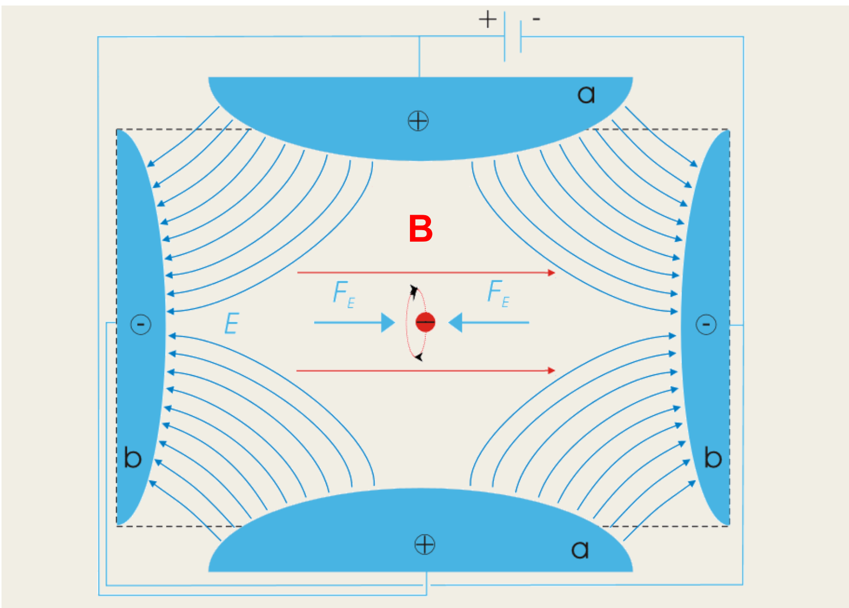
Penning gauge allows to differentiate He & H2 spectroscopically

Goal: understand discharge behavior and optimize light output for optically assisted Penning gauge which uses the local magnetic field of the device

Penning trap principle

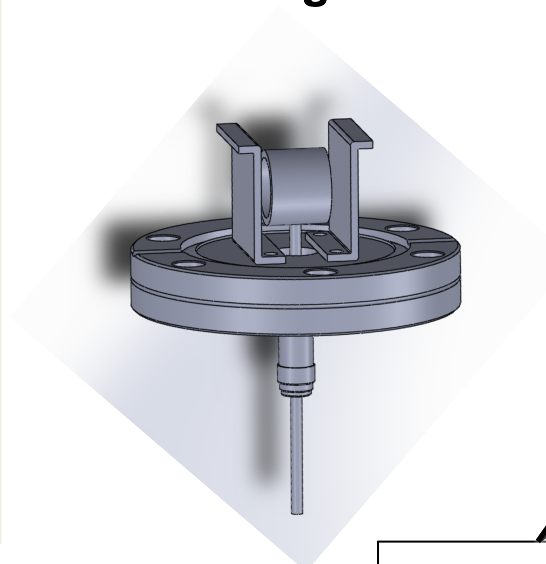


Ion current ~ n_n

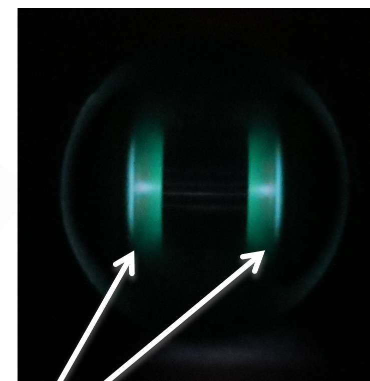
Existing penning trap

[R. Raman et al., RSI **74** (2003) 1900]

mounted at NSTX-U has been rebuild for testing



1 x 10^{-3} mbar, 3 kV



Light for spectroscopy

Quite low intensity ⇨ Low sensitivity

Approach: evaluated existing setup and try to change anode configuration for better light throughput

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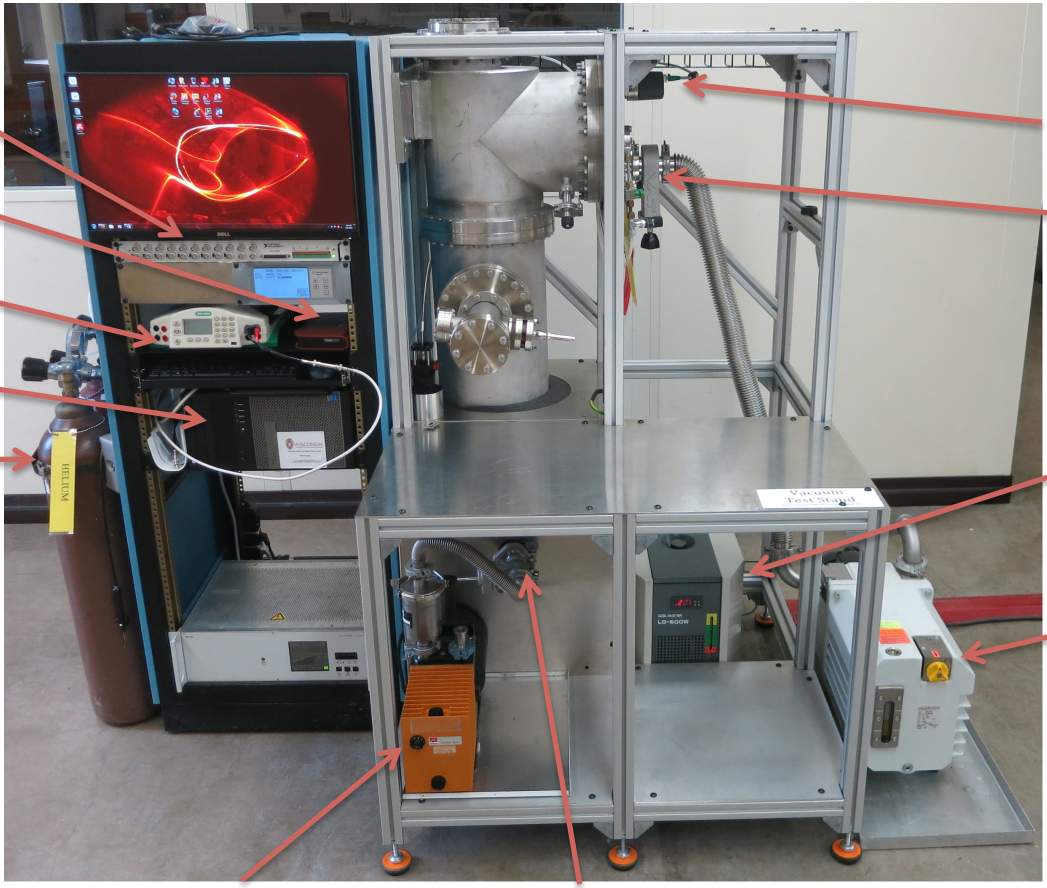
Test environment for optimization of Penning Gauges has been setup

Goal: provide high quality ($<10^{-9}$ mbar l/s leak rate) vacuum test environment



Test stand ready and it was used for detailed characterization of presently mounted Penning Gauge

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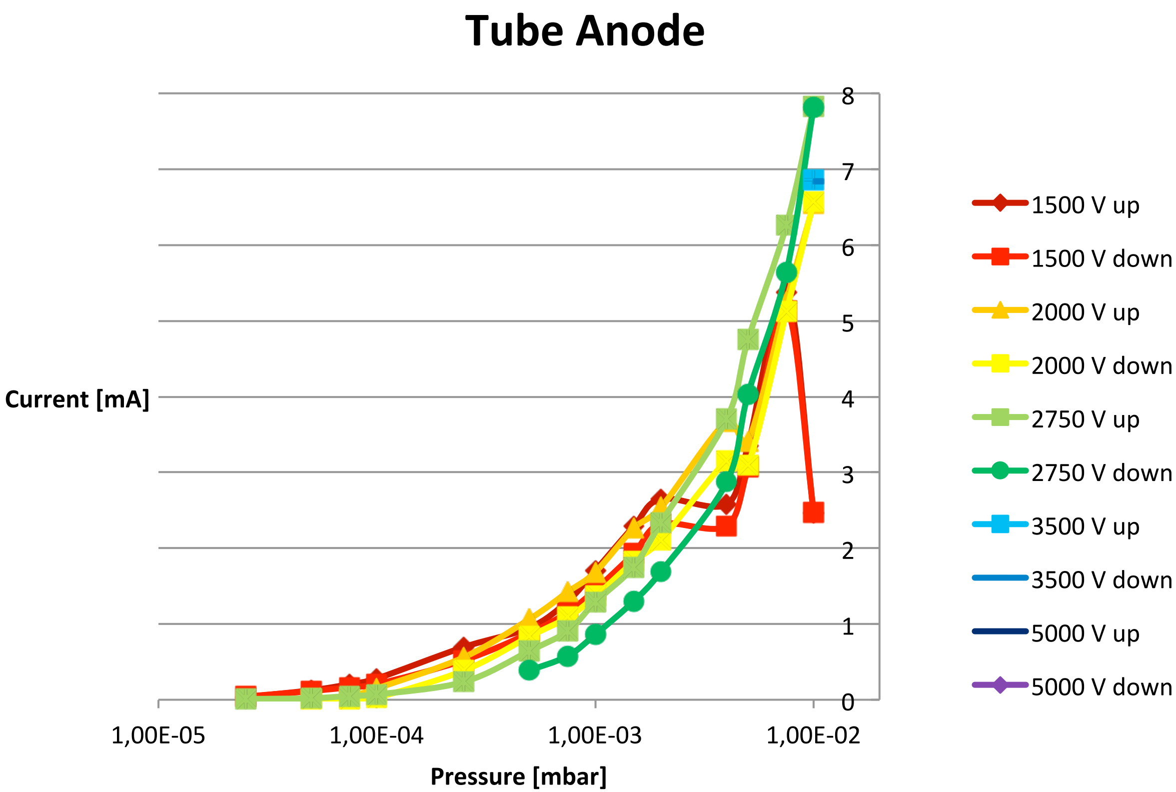
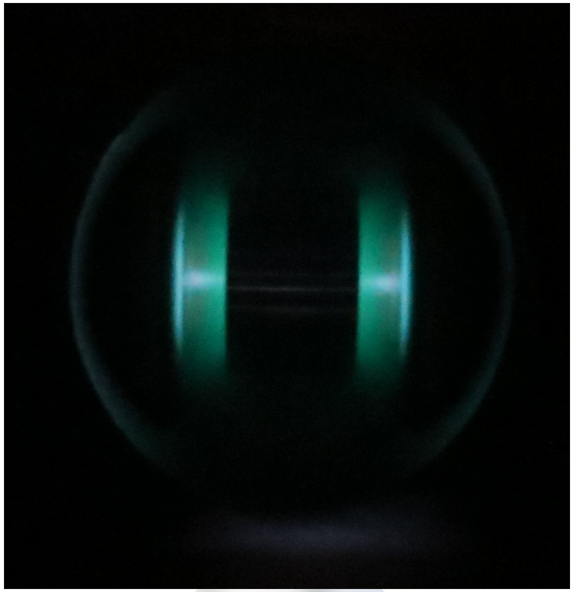
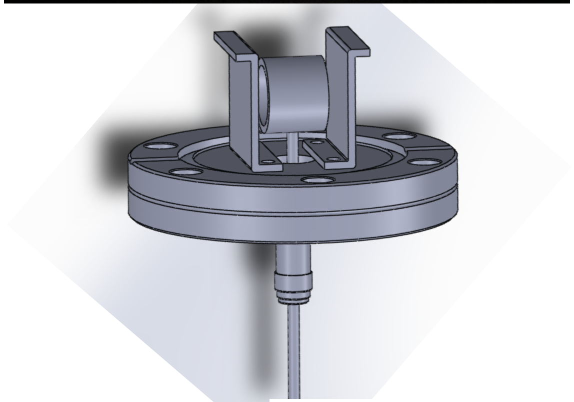
Existing NSTX-Upgrade Penning Gauge was characterized

Features: stable discharge, good current/pressure sensitivity,
but: moderate light







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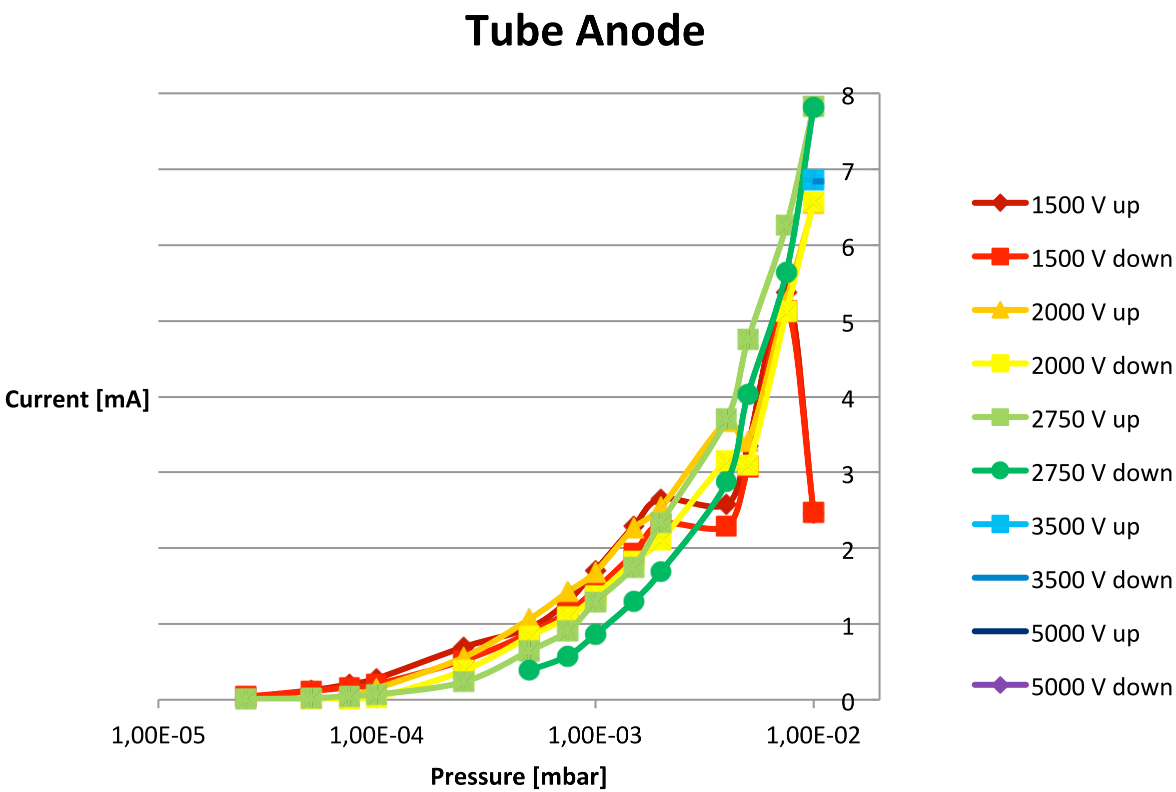

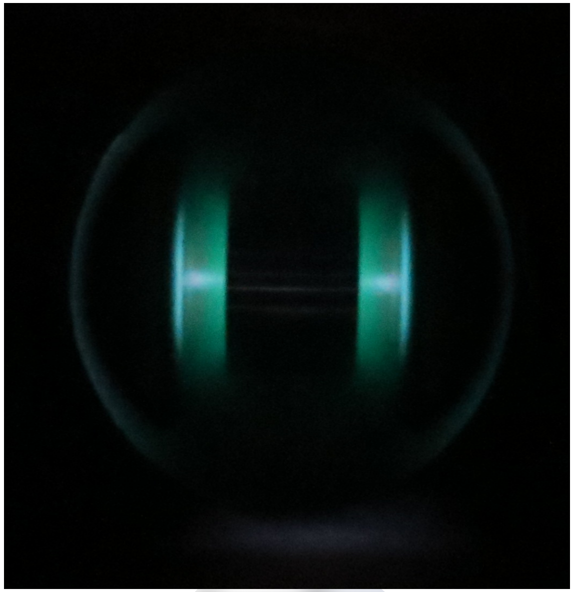

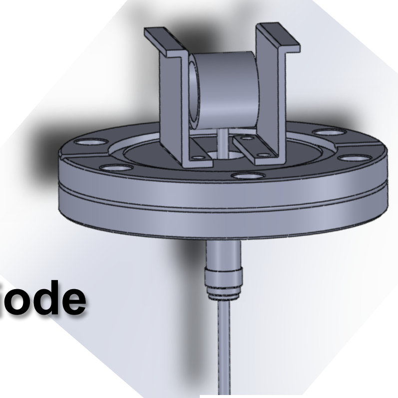

Next step: reactivate setup at NSTX-U and use photo diode and filter for light detection (with V. Soukhanovskii)

Summer visit K. Flesch to be scheduled

In parallel: develop new anode and (later) replace existing

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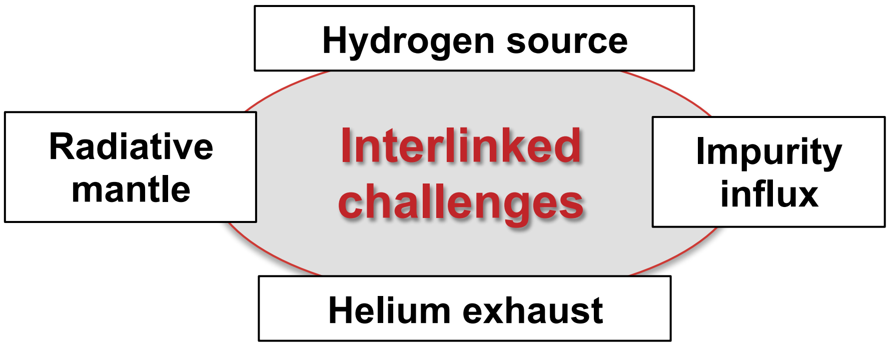

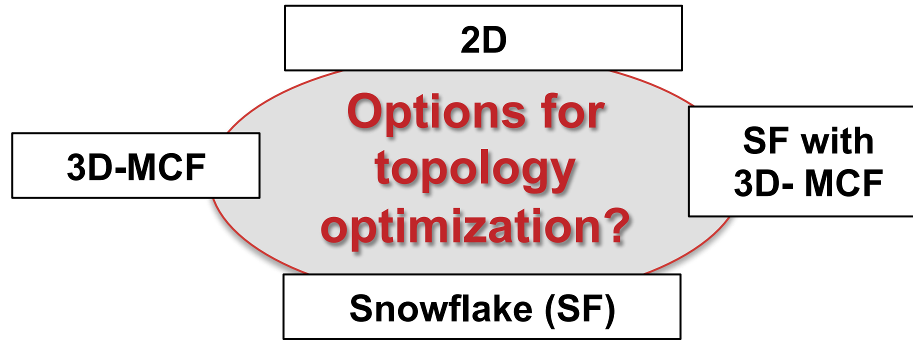

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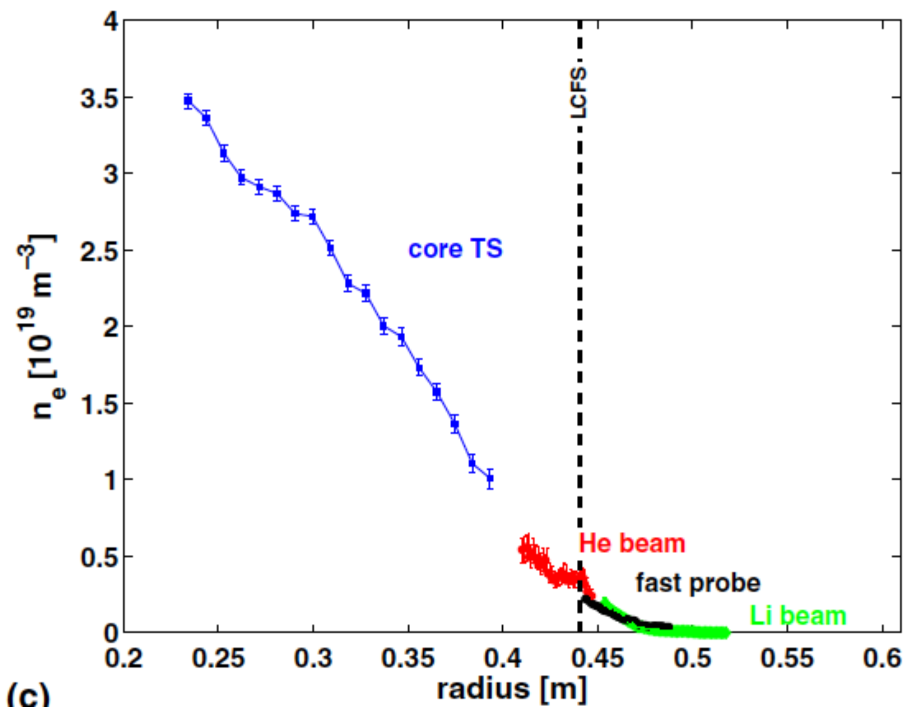
Line ratio spectroscopy on He is a reliable method for plasma edge characterization

Available parameter range: $2.0 \times 10^{18} m^{-3} < n_e < 5.0 \times 10^{19} m^{-3}$, $10 \text{ eV} < T_e < 350 \text{ eV}$

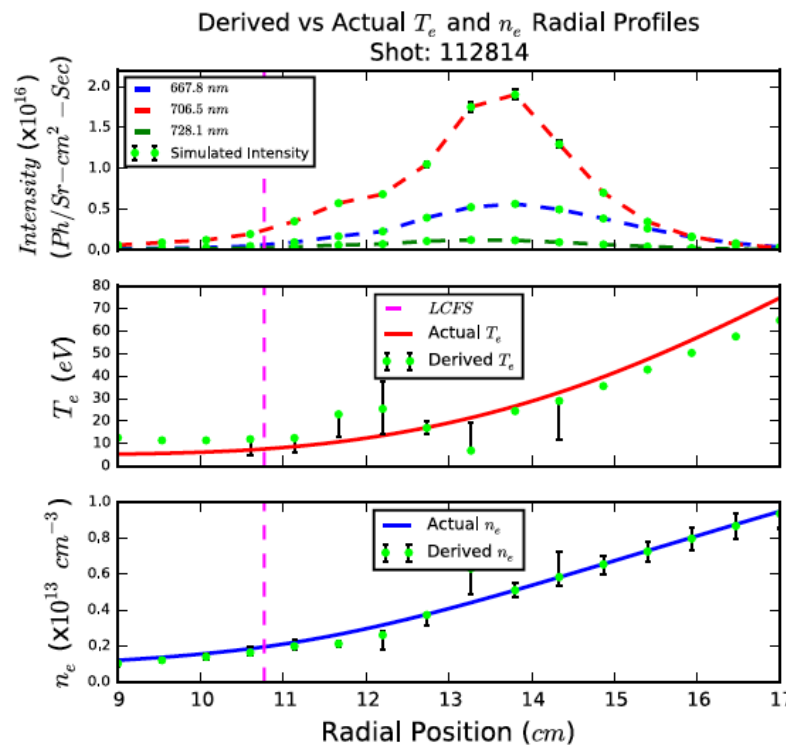
Regularly applied on several device

- **TEXTOR** [O. Schmitz et al., PPCF **50** (2008) 115004]



Used as standard diagnostic at RFX
(see talk by M. Agostini in June 2015)

Feasibility study for NSTX-U promising



[J. Munoz-Burgos et al., PoP **23** (2016) 053302]

Advanced He CRM is ready to be deployed!

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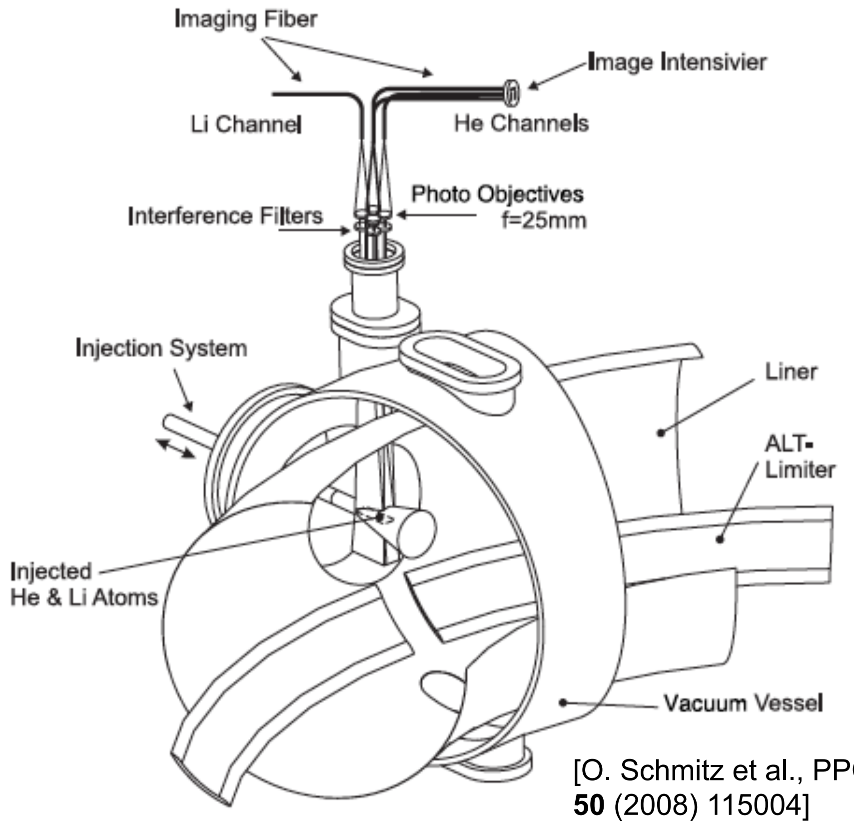
Hardware implementation is quite simple and existing key components would allow system setup on short time scales

TEXTOR implementation



[O. Schmitz et al., PPCF **50** (2008) 115004]

Figure 1. Setup of the combined Li and He thermal atomic beams.

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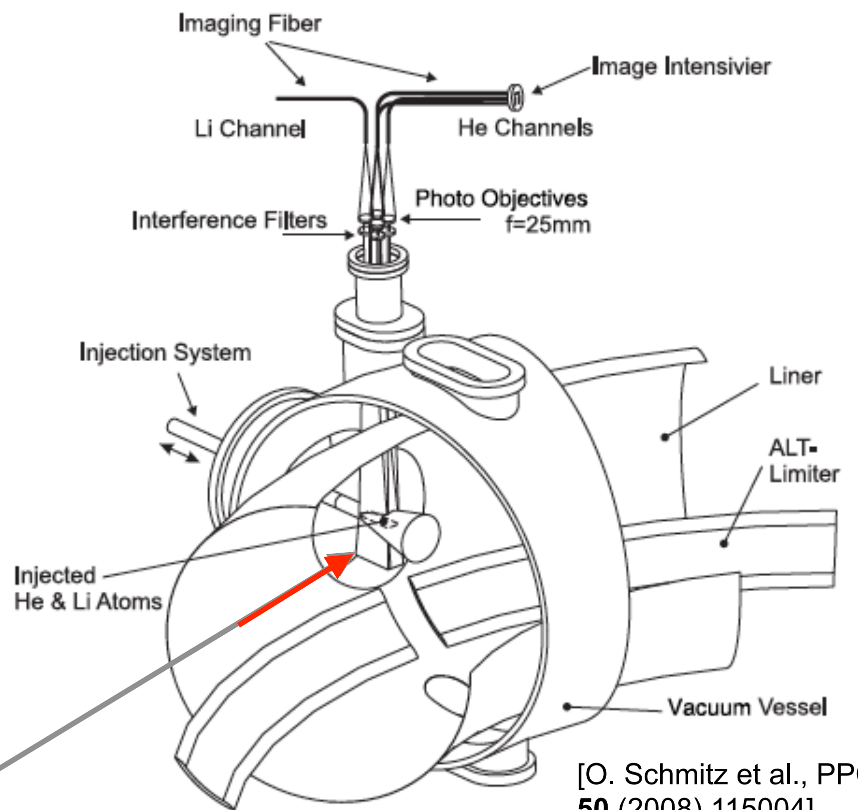

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Figure 1. Setup of the combined Li and He thermal atomic beams.

Nozzle

- GPI
- TEXTOR inlet
- Piezo valve W7-X

available

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Optical unit

available

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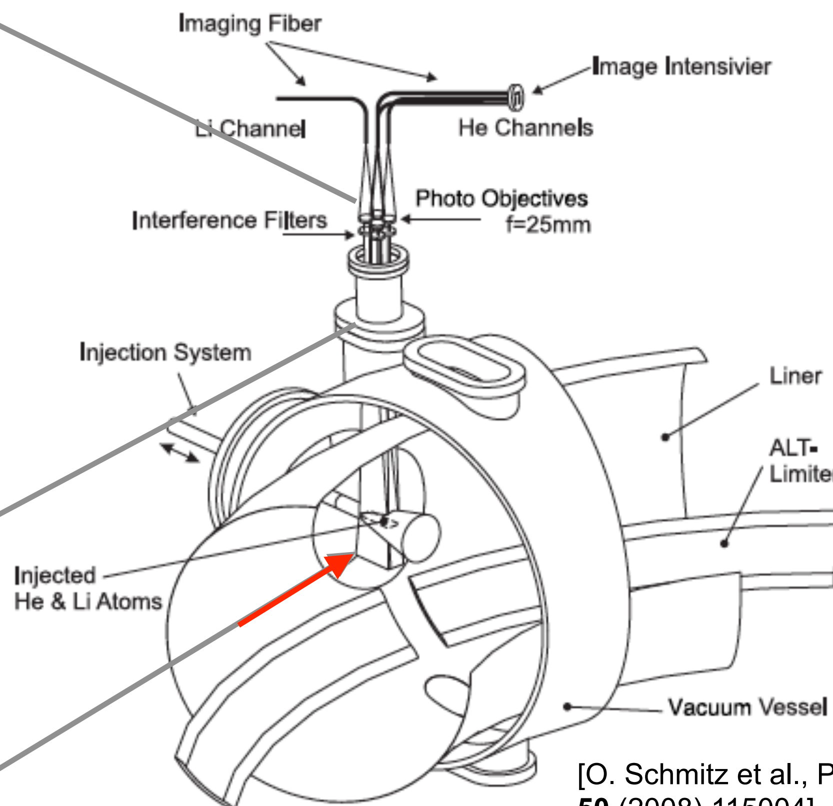

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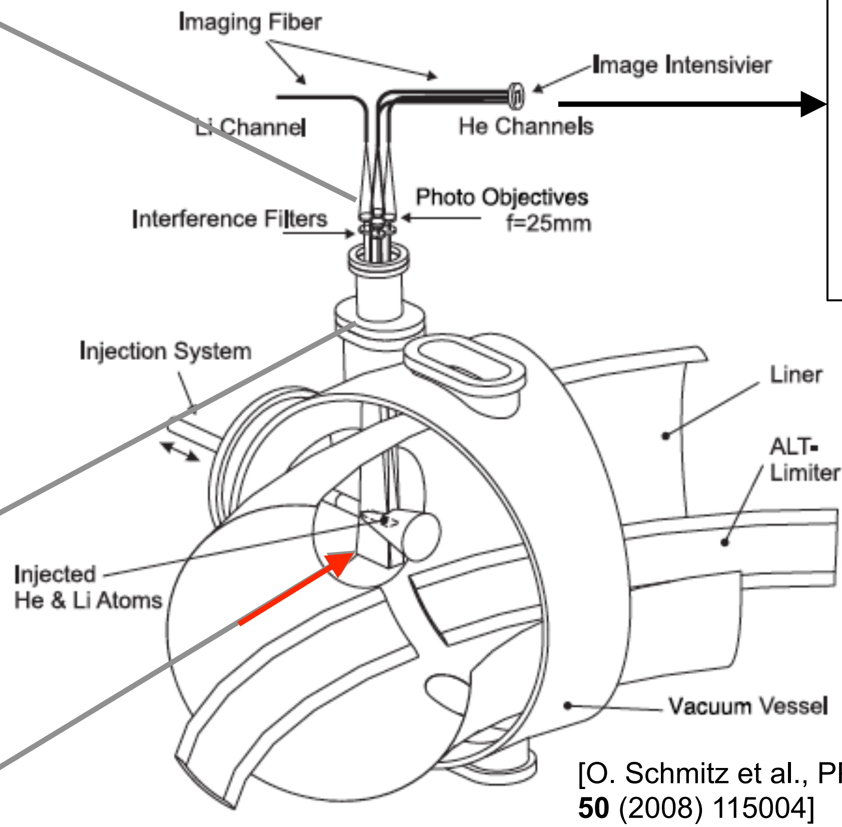

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Spectroscopy

- Imaging fibers
- Filtered cameras
- Filter-scopes
- RFX diodes
- spectrometer

Special goal

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Contr. K. Flesch

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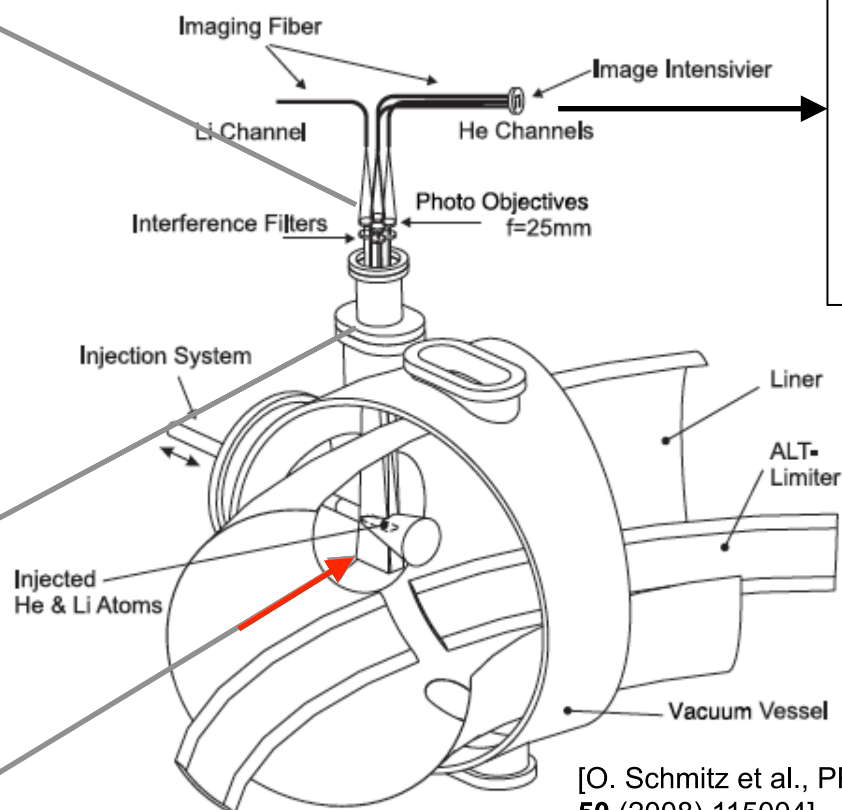

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International team and hardware components are ready

How to best approach a feasibility test?

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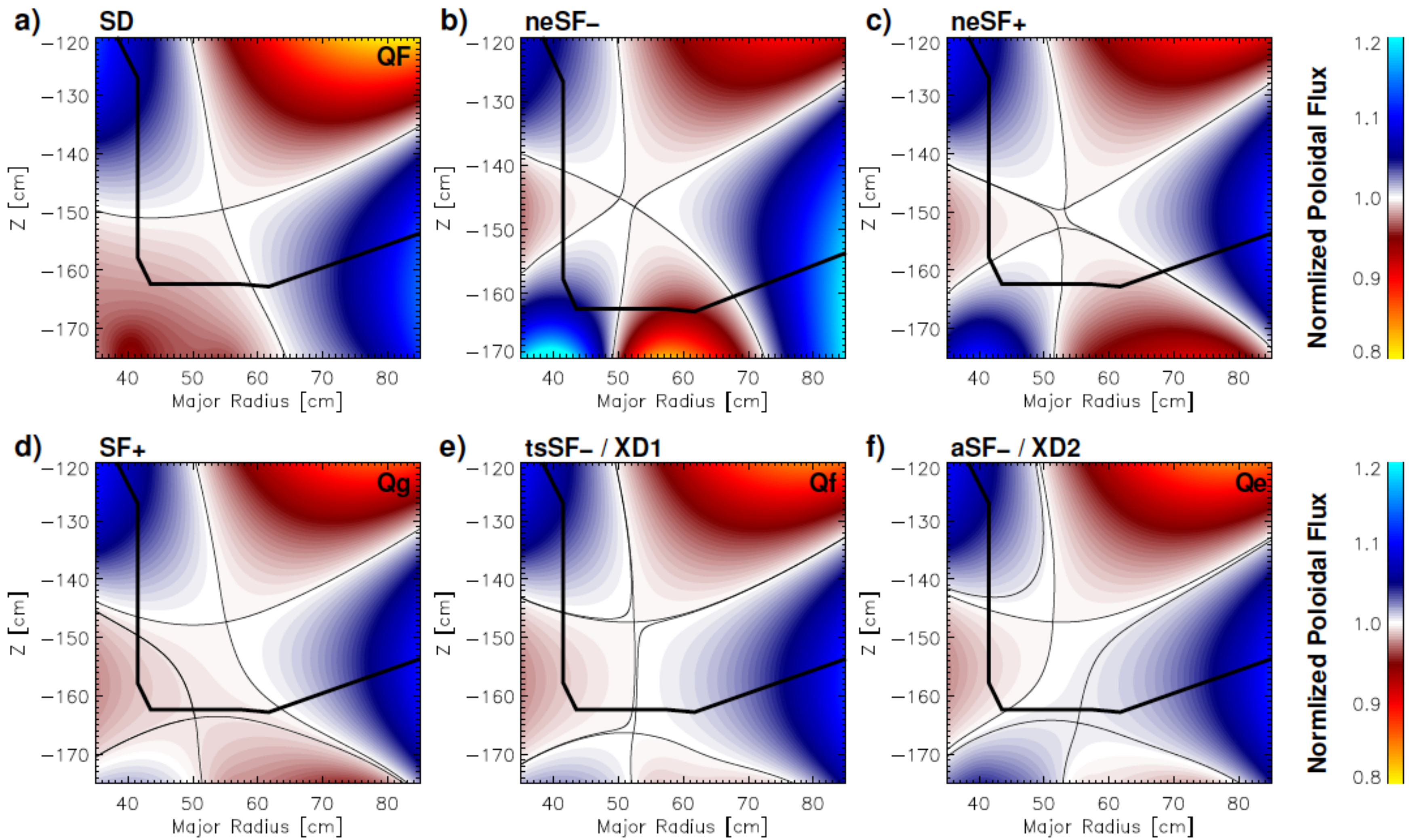
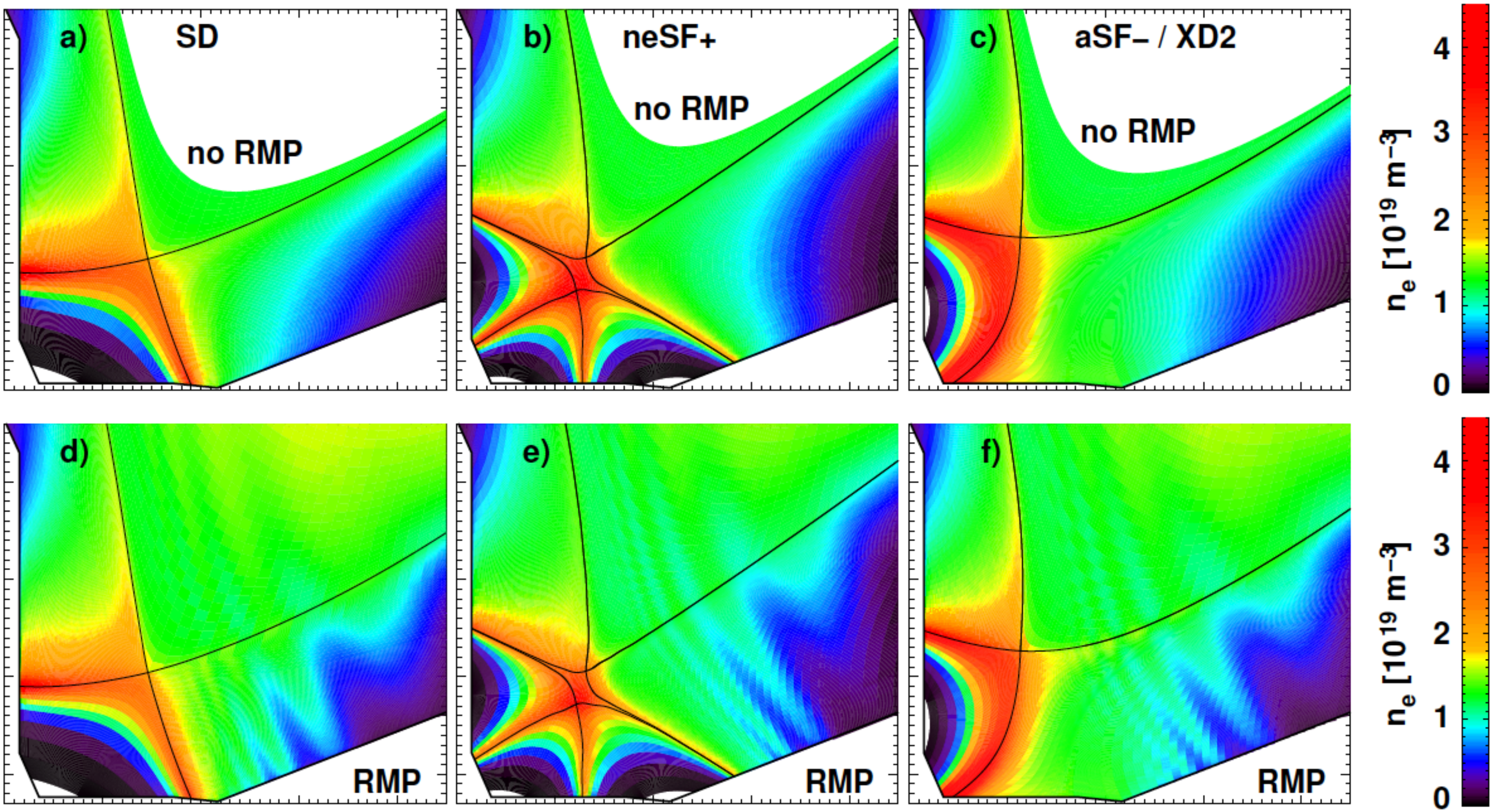
EMC3-EIRENE grid generator was enhanced to make code compatible with all NSTX-U divertor configurations under consideration



[H. Frerichs et al., "Exploration of magnetic perturbation effects on advanced divertor configurations at NSTX-U" PoP (2016) submitted]

[H. Frerichs et al., talk on Spherical Tokamak Workshop, PPPL, 2015]

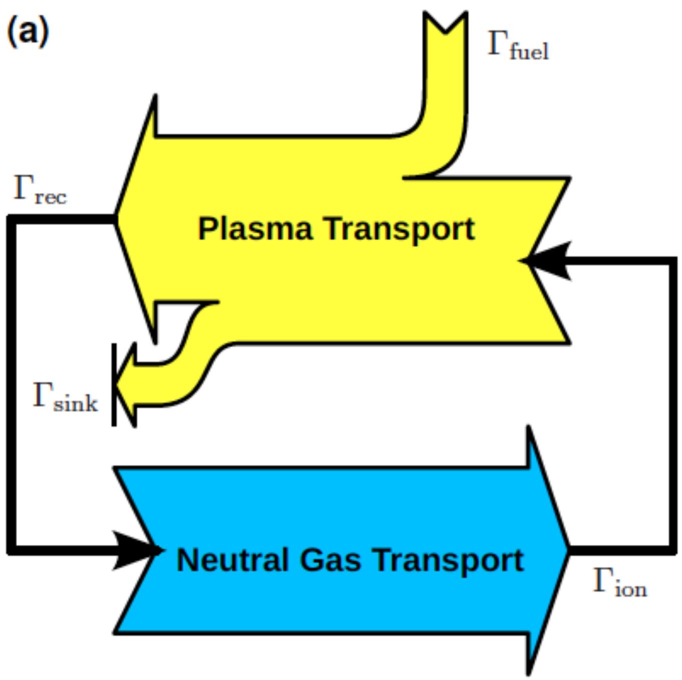
Impact of RMP fields has been assessed and 3-D boundary effects have been studied – important groundwork for PhD student



Combination with MHD code enables to assess plasma response effects (coupling to M3D-C1 was implemented)

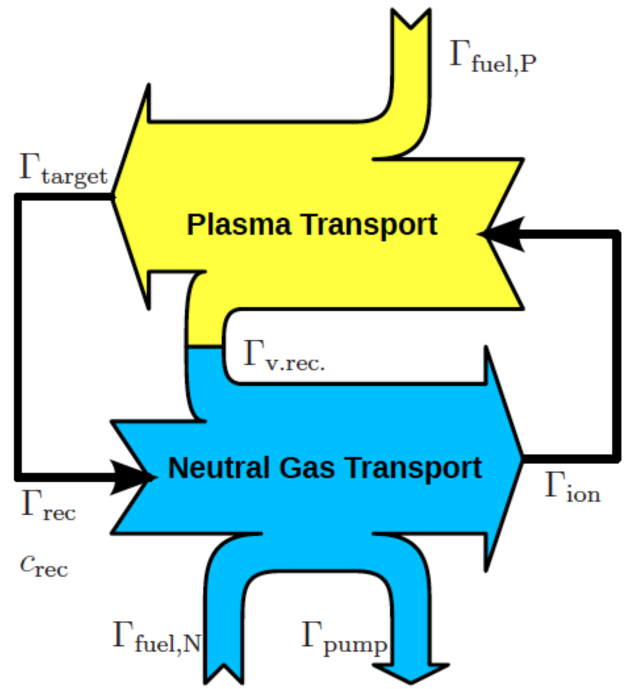
New, advanced particle balance implemented into model enables more versatile treatment of neutral source sand sinks

Scaled particle balance



- No separate sources and sinks
- Density scaled to source and v.v.
- No volume recombination possible

Advanced particle balance



- Explicit sources and sinks
- Local gas injection and pump
- volume recombination

Code stability at detachment: NSTX-U excellent test bed

- Needs more attention from numerical scientist
- Exploit synergy with M3D-C1 activities by G. Canal

Summary and action items to move forward

- Activities are on schedule
- Two PhD students are nearly out of credit requirements and ready to engage 100% on research full time for NSTX-Upgrade
- Numerical Scientist has prepared ground for configurational versatility in EMC3-EIRENE and code stability at high density is being enhanced
- Synergism on MHD response with M3D-C1 activities by G. Canal, T.E.Evans et al. allow to shift weight from NIMROD to EMC3-EIRENE enhancement
- Penning gauge development promising and scheduled to conclude this year, plan for implementation next year needs to be made
- He line ratio project in standby, plan for feasibility test with existing hardware or with feasible modifications should be made

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APPENDIX

Physics ingredients to tackle neutral fueling and exhaust challenge

Single reservoir, single species particle balance is initial step to analytically quantify neutral control capability of entire system

$$\frac{dN_{tot}}{dt} = -\frac{N_{tot}}{\tau_p} + f_{rec}\,\Phi_{rec} + \Phi_{ext} = \Phi_{ext} - \Phi_{pump}$$

$$\Phi_{ext} = f_{NBI}\,\Phi_{NBI} + f_{gas}\Phi_{gas}$$

Key measurement parameters:

- **Electron density and temperature**
- Neutral fluxes
- **Neutral density (hydrogen & impurities)**
- Neutral pressures

Key parameters derived:

- Perpendicular transport (DC time scale)
- Plasma and impurity source distribution
- Fueling efficiencies
- Exhaust efficiencies and pumping speeds

An analytical multi-species, multi-reservoir particle balance model is required for direct quantitative interpretation of relevant quantities in the experiment

EMC3-Eirene will be used together with experimental measurements to develop and implement such a model

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Methods proposed add key measurements to supply critical experimental information to the challenge of neutral and impurity fueling and exhaust

Stage I: experimental methods will be enhanced and adapted for purpose

Enhanced characterization of edge and divertor plasma	→ Line ratio spectroscopy on helium & lithium
Partial neutral density and neutral pressure measurement	→ Spectroscopy on Penning gauges

Stage II: application of state of the art modeling tools is key to project

3D edge plasma and neutral transport modeling	→ Enhanced EMC3-Eirene
	Enhanced version with localized source/ sink and volume recombination
3D MHD modeling of plasma response	→ NIMROD

Proposal includes

- using NIMROD response field in EMC3-Eirene
- **NIMROD modeling** of **edge stability with Snowflake** and **Snowflake with 3D-MCF**

Proposed time line of project

2014	2015	2016	2017

Task 1: EMC3-Eirene with puff/pump@ NSTX-U
1st PhD Project, PI

- Implement
- Explore exhaust features with 3D edge
- Interpretative Modelling of Experiment

Task 2: NIMROD Plasma Response Modeling
Scientist Project, co-I

- Implement
- Compare to IPEC and M3D-C1
- Implement 3D plasma response fields in EMC3-Eirene and validate

Task 3: Experimental assessment of neutral and helium transport and exhaust
2nd PhD Project, PI

- Qualification of Penning spectroscopy (test stand)
- Implement Penning spectroscopy (helium partial pressure) and apply in experiments

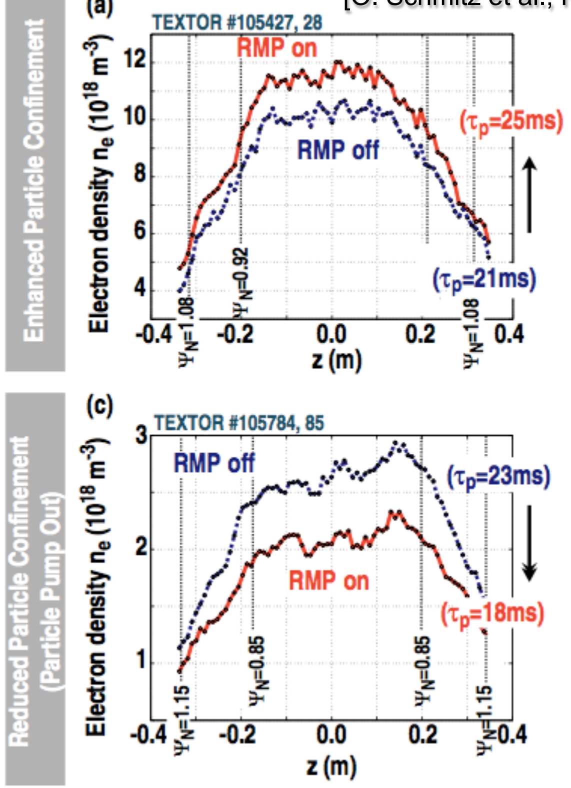
Prepare and conduct line ratio spectroscopy on helium

Prepare, execute and analyse experiments at NSTX-U

Motivation – is that feasible at all? Yes, at TEXTOR dedicated control of density and impurity exhaust by 3D fields has been demonstrated

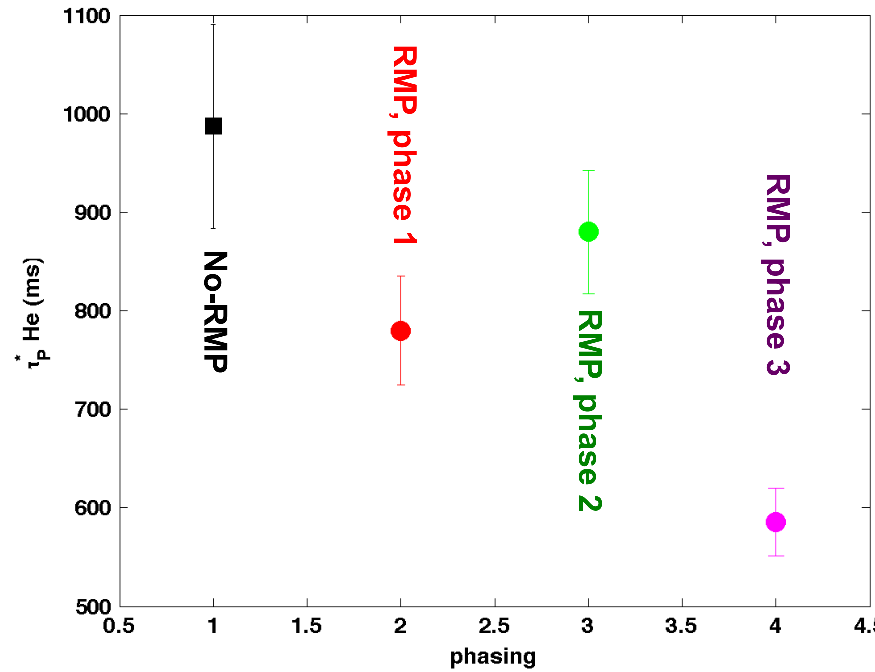
Density control by 3D fields

[O. Schmitz et al., NF 52 (2012) 043005



Enhanced helium exhaust

τ_p* for helium in plasma edge



At NSTX-U, we can make an integral approach on this and address density control by 3D-MCF as key issue for ST based test facilities

Helium exhaust as key question for burning plasma devices can be addressed with methods and tools developed and applied

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