Initial operation of the NSTX-U Real-Time Velocity diagnostic

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PPPL, Room B318
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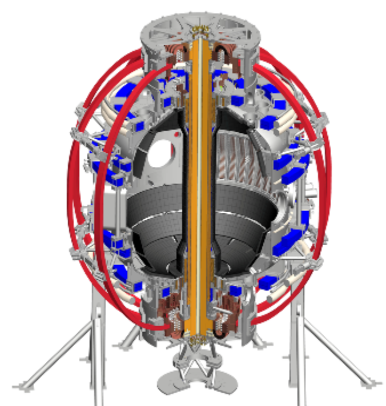
see draft Rev. Sci. Instrum. at http://nstx.pppl.gov/DragNDrop/Draft_Paper_Review/



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Outline

- The RTV system
  - Main parameters
  - Present status
- Analysis of RTV data
  - Post-discharge and real-time analysis
  - Spectra contamination by second NBI line
- Example of physics studies that benefit from RTV
  - Sawteeth, MHD effects on rotation
- Summary & outlook

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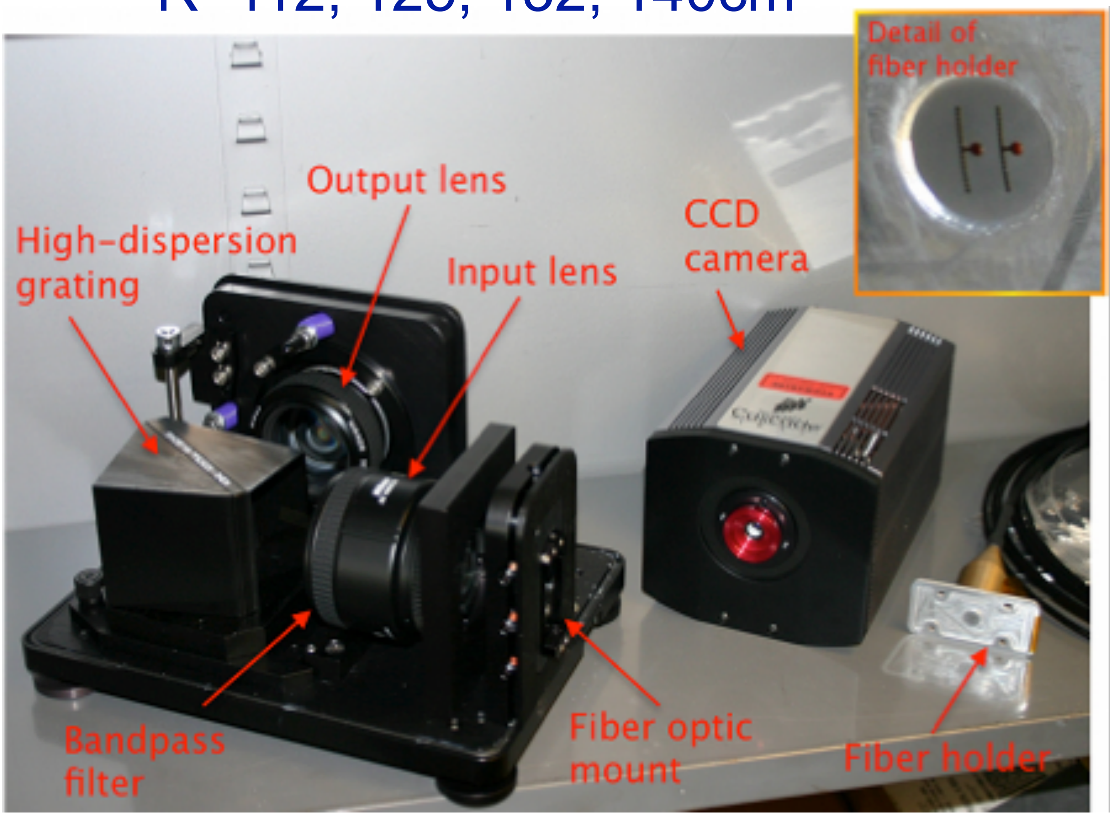
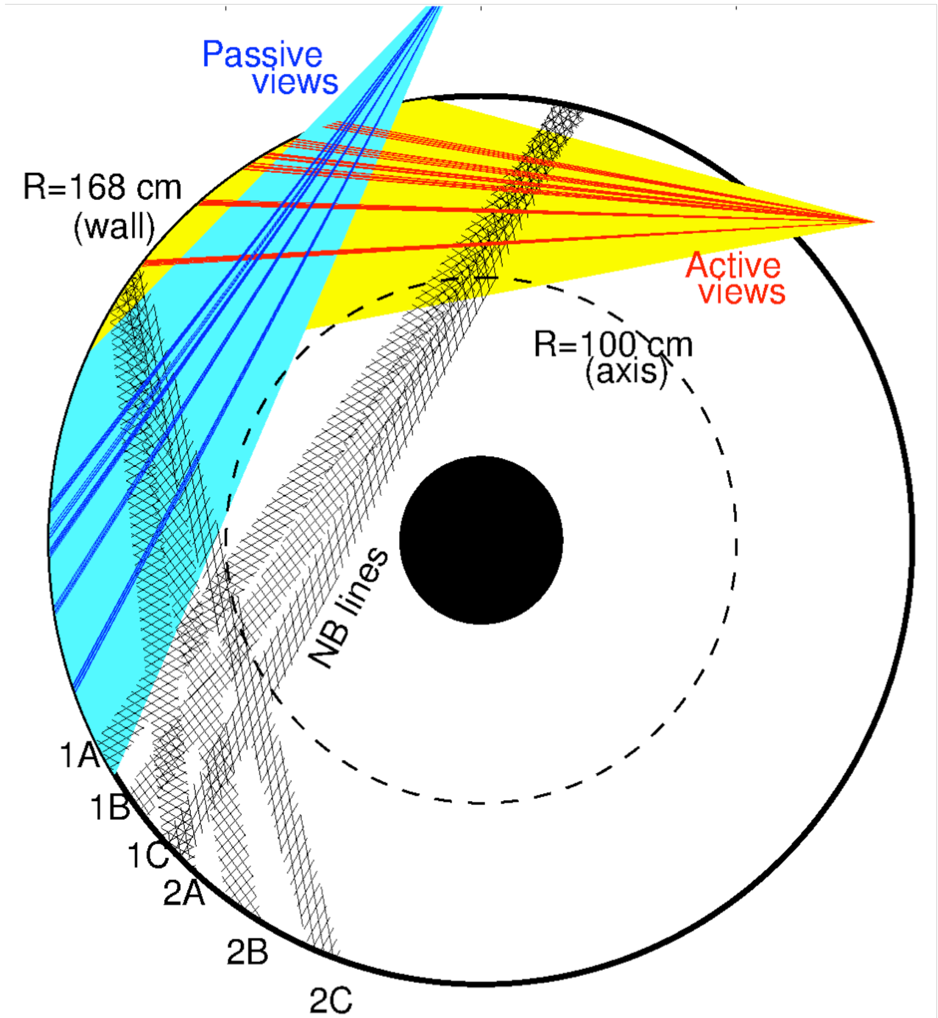
Real-Time Velocity (RTV) is a fast system based on active spectroscopy

- System based on active charge-exchange spectroscopy (NB1 line)
- Monitor C VI, n=8-7 line @ 5291nm
- RTV views interleaved with CHERS views at midplane
- 4 views available
  - R=112, 125, 132, 140cm





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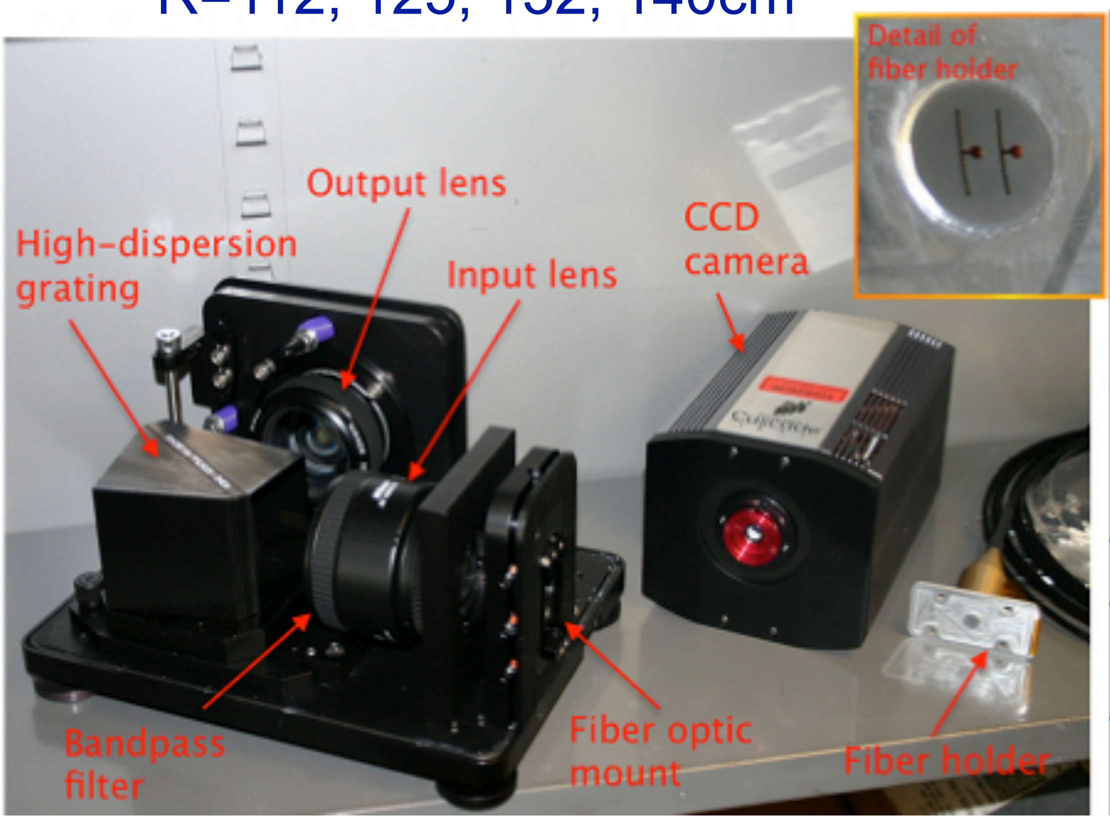
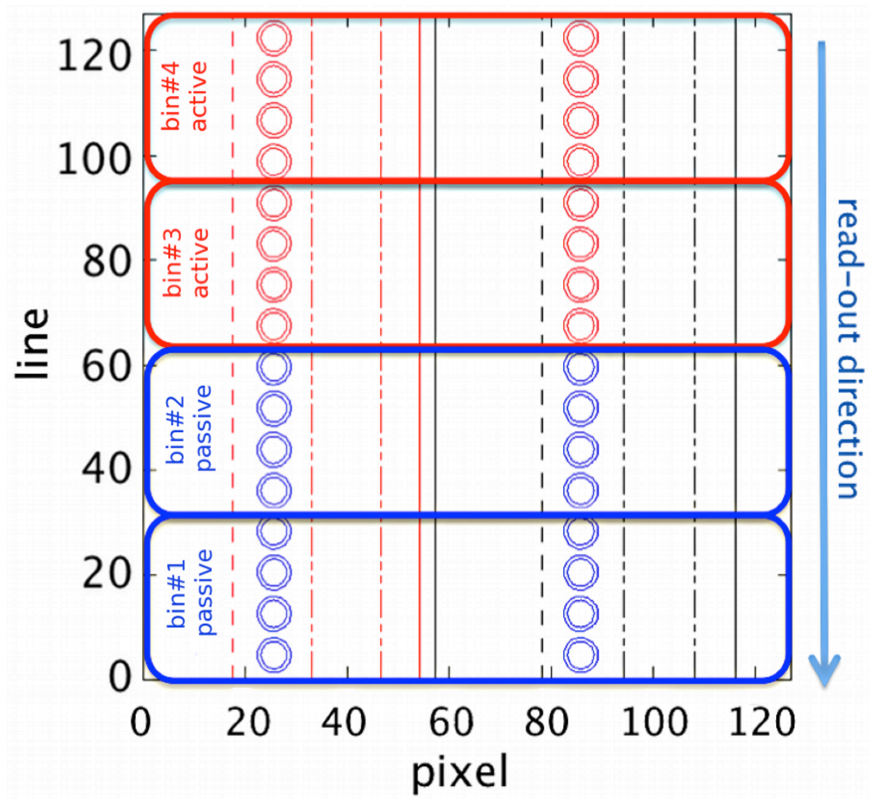


Fiber arrangement on each of two (identical) systems:



- 7-8 fibers aiming at same R
- Each "channel" has active/background views pair
- Simplified system for higher sampling rate: no chopper, no entrance slit

RTV complements CHERS information with high temporal but low spatial resolution data

System	CHERS	RTV	
Channels	51 (39)	4 (4)	*
Fibers/channel	2 (1)	8 (7)	
Chan. radii [m]	0.85-1.55	1.1,1.25,1.35,1.4	
Frame rate [kHz]	0.1	$\leqslant 5$	*
Measurements	v_ϕ, T_C, n_C	v_ϕ, T_C (n_C)	*
Monitored line [Å]	C VI, 5290.5		
Dispersion [Å/pixel]	0.21	0.43	
Instrum. width [keV]	0.1	0.2	*

TABLE I. Main parameters of the CHERS and RTV systems. Values in parenthesis refer to the background views. For RTV, n_C data are are available only from post-discharge analysis. (Additional RTV views are installed at $R = 137, 145$ cm [10] but are not used in the present work).

**Achieved performance meets or exceeds requirements for real-time v_ϕ control*

[M. Podestà, RSI (to be submitted 2016)]

Diagnostic was first tested in FY11; Up & running since NSTX-U CD-4

- RTV systems assembled in 2011
  - Tested with Ne lamps, He glow; calibrated *[M. Podestà, RSI **83** 033503 (2012)]*
- Acquisition and analysis software improved after first data from NSTX-U plasmas
  - Demonstrated RT analysis for v_ϕ, possibly T_i (limited to T_i>150eV)
  - Developed post-discharge analysis tools
    - v_ϕ from real time analysis available right after shot
    - Quick analysis (v_ϕ, T_i) available ~1 minute after shot
    - Full analysis (CHERS-like: v_ϕ, T_i, n_C) available ~5 minutes after shot
- Implemented & tested data transfer to PCS
  - Thanks to PCS Group!

➢ *Data now routinely available to develop & test v_ϕ control algorithm(s) in PCS*

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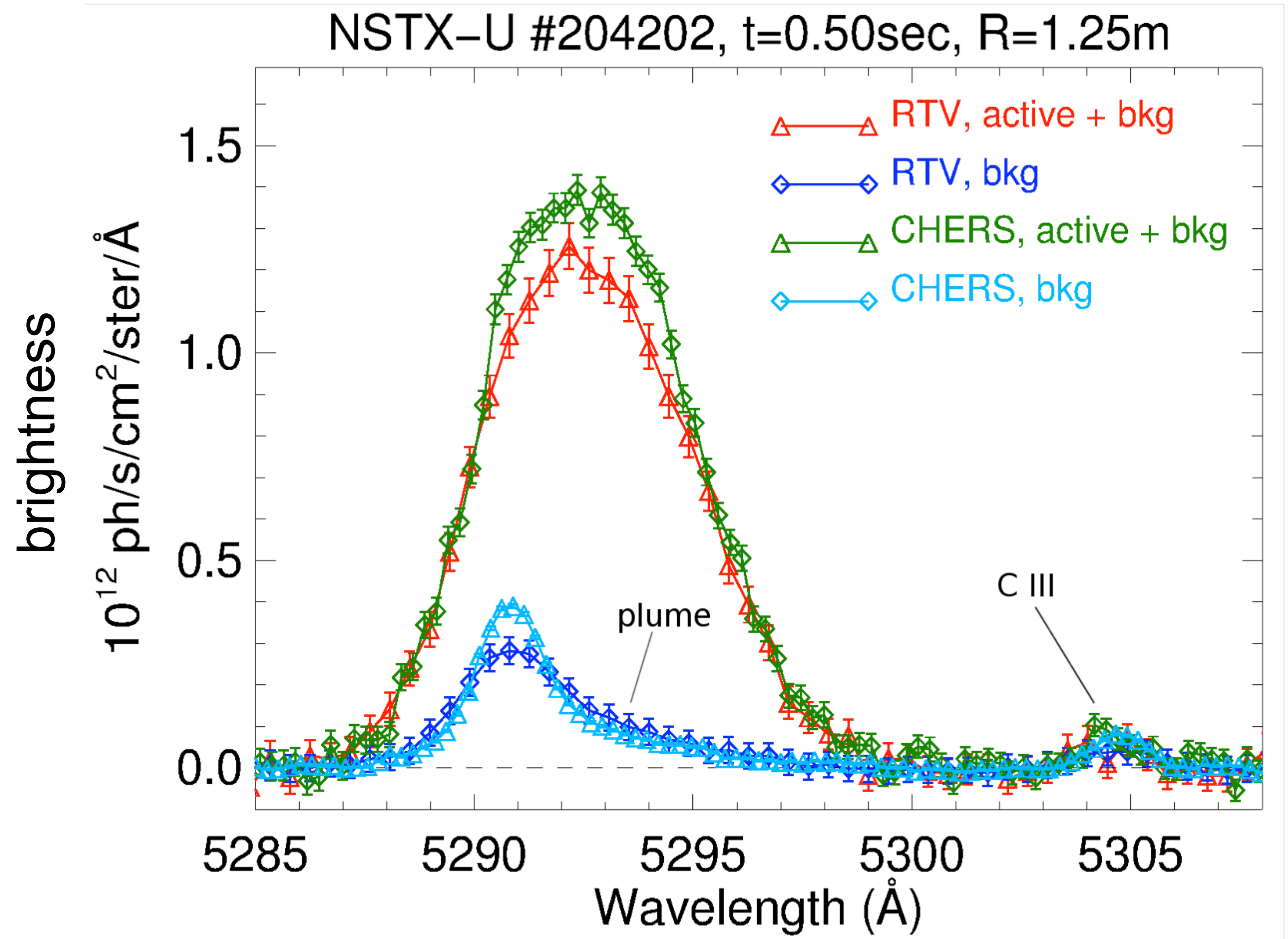
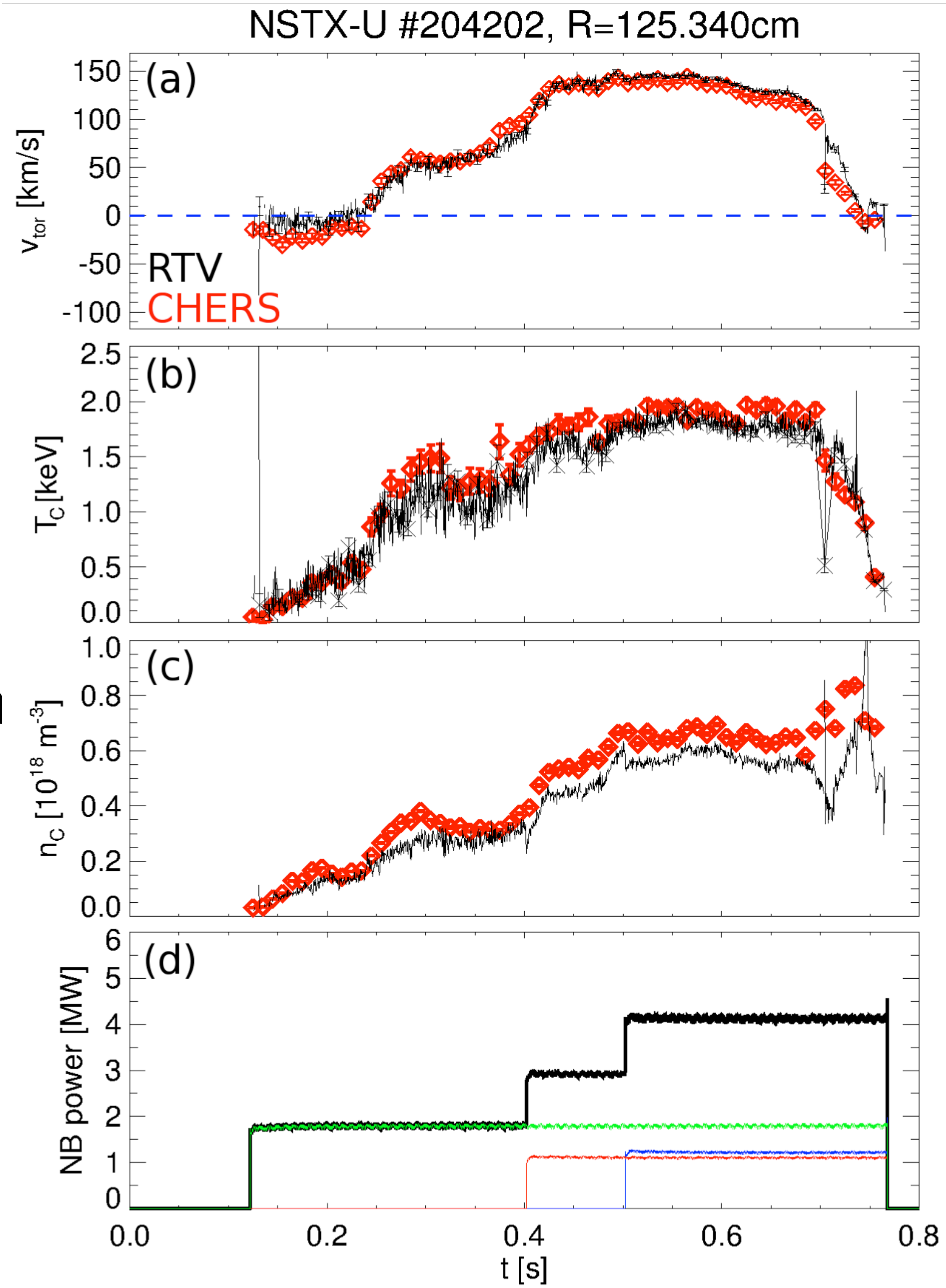
Measured spectra feature good S/N ratio for P_{NB}>2MW; P_{NB}~1MW marginal but measurable



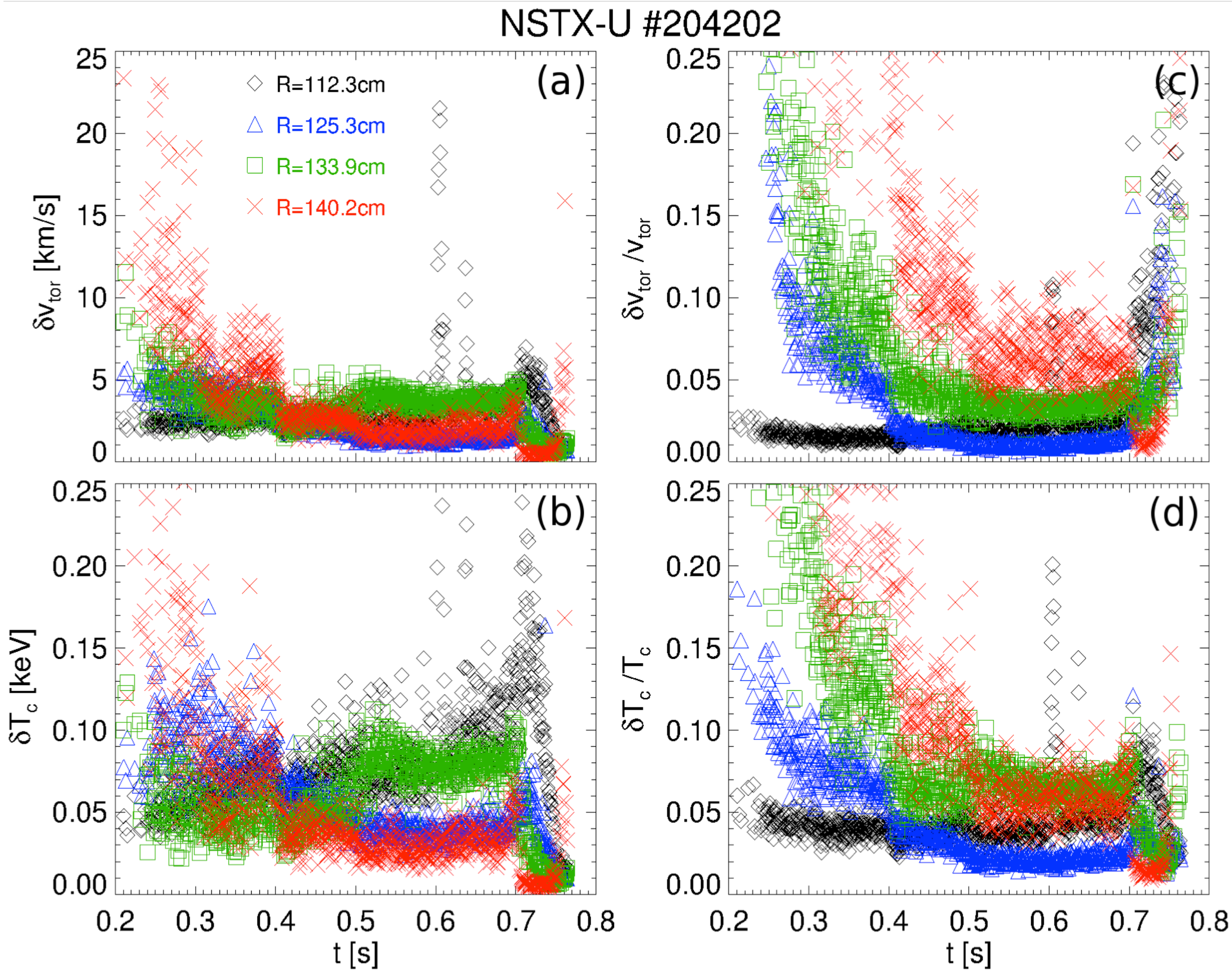
- Shown here is CHERS @100Hz vs RTV @2kHz for P_{NB}~4.2MW
- All typical feature appear in RTV spectra
  - Active CX component, background, plume, C III
- Plume contribution removed during RT analysis for core channels

Post-discharge analysis compares well with CHERS results

- NSTX-U #204202
- P_{NB} increases from 1.7MW up to 4.2MW
- Mid-radius channel, R~125cm
- Low carbon content
  - Z_{eff}~1.2-1-5 from CHERS
- Good match for v_ϕ, T_i at all four RTV radii
- Larger discrepancies >20% for carbon density
  - Suspect uncertainties in RTV vs. CHERS absolute calibration (performed summer 2014!)
  - Spot size is different (larger for RTV)
  - Also: window coating at Bay B-mid?
  - *Analysis relies on MPTS for n_C analysis: lower "effective" time resolution*



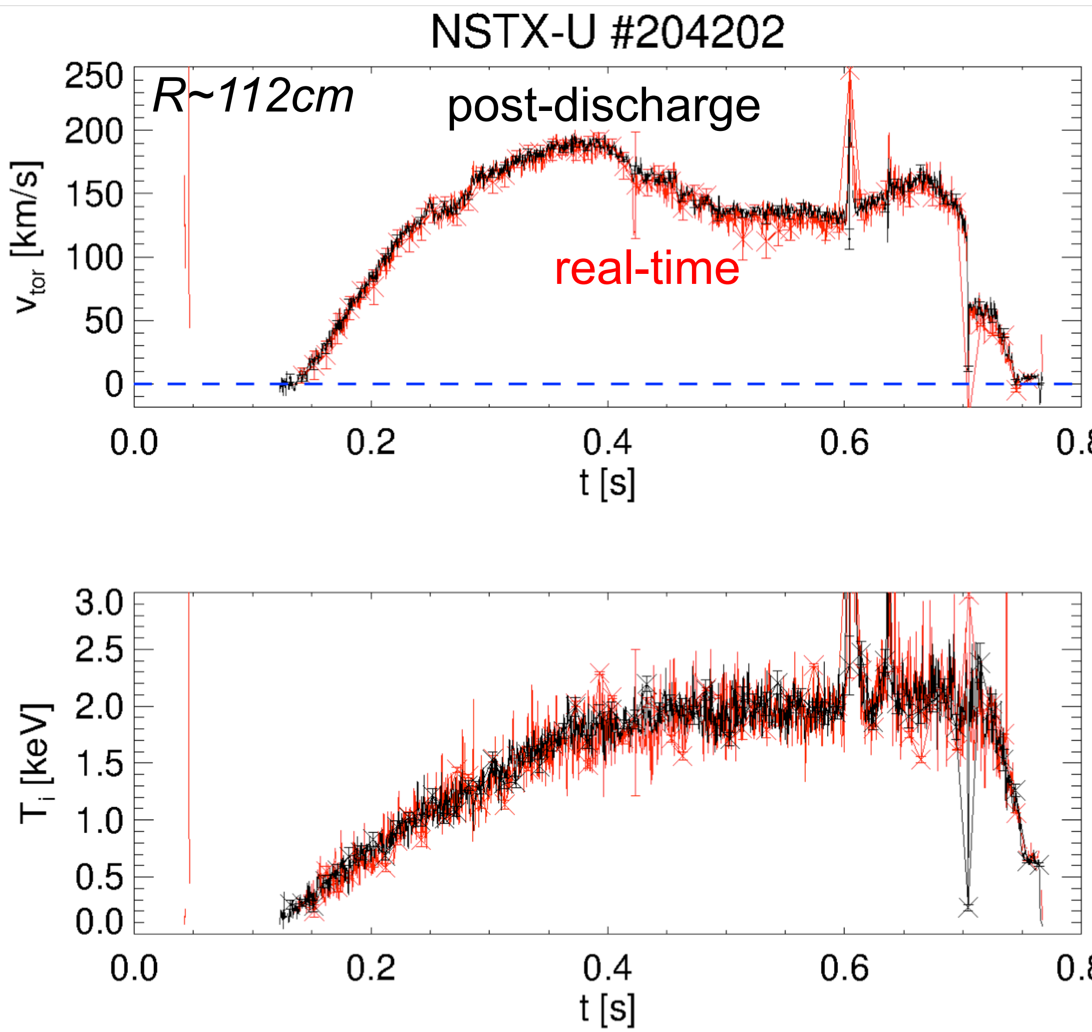
Uncertainties on velocity, temperature are <10% when P_{NB}>2MW



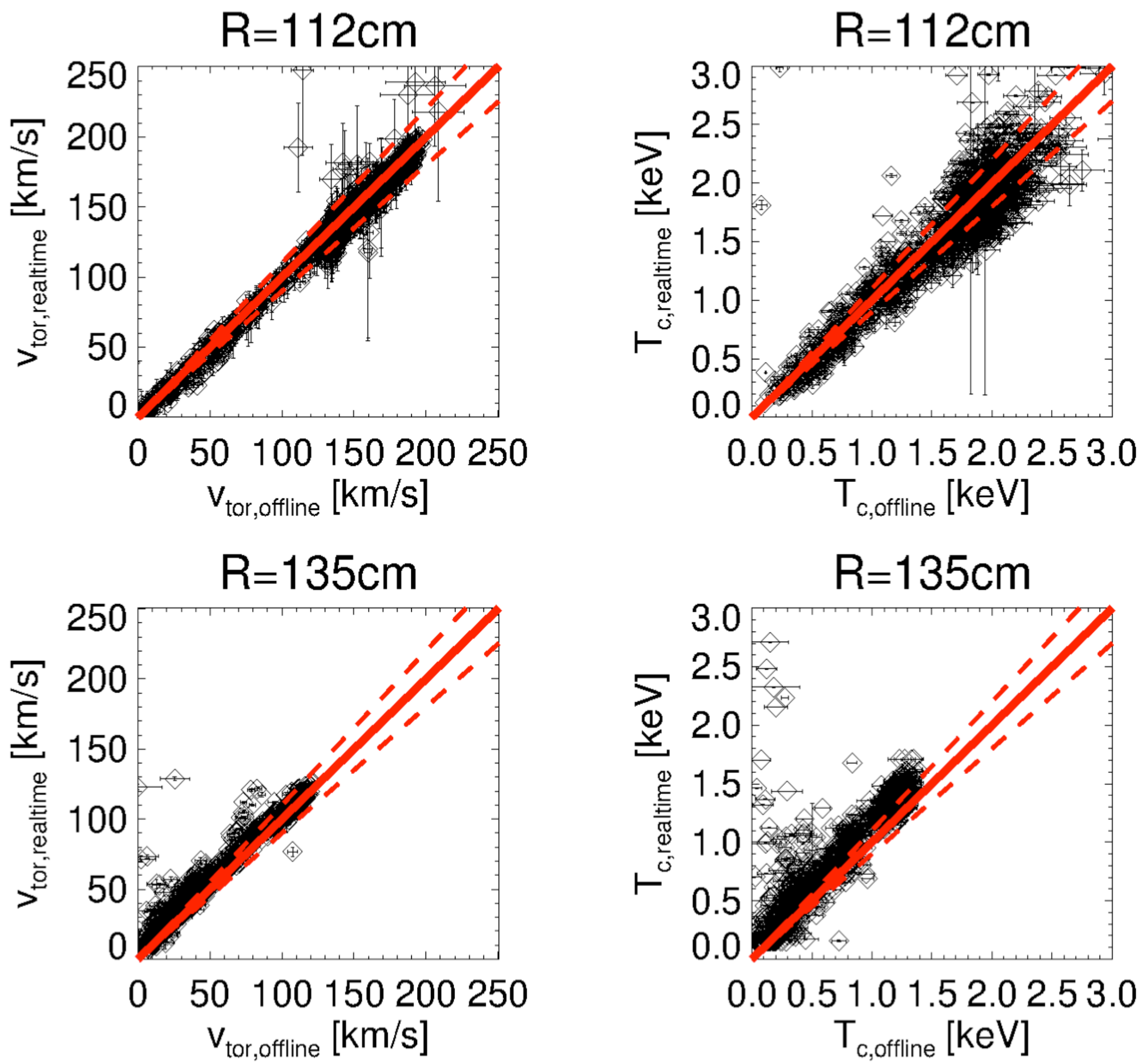
- Absolute & relative uncertainties within expected range
- Relative uncertainties <10% for sufficiently high P_{NB}

Real-time analysis provides accurate data for rotation feedback (and more) /1

- Good match for both v_ϕ and T_i between real-time and post-discharge analysis
- Larger uncertainties for RT analysis (as expected)
  - Simplified analysis
    - E.g. to account for instrumental function, plume contribution, background baseline
  - Reduced number of fit iterations



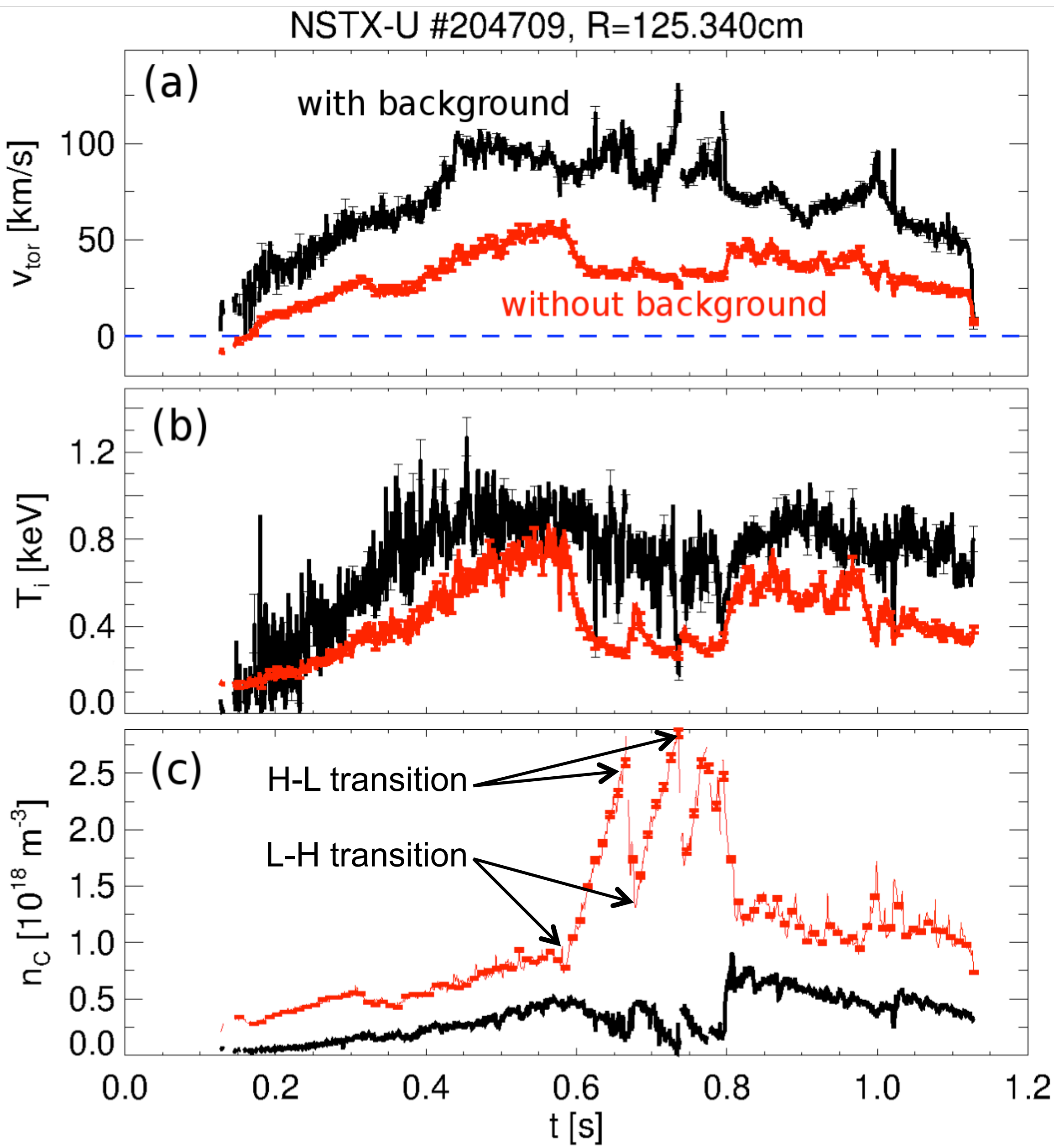
Real-time analysis provides accurate data for rotation feedback (and more) /2



- Agreement with post-discharge analysis is typically better than 20%

Background measurements are critical for reliable RTV results

- Paired active/background views are key for successful background removal in real time
- Results off by 2x or more if no/negligible background is assumed
- *Drawback: background views intercept second NBI line*
  - *No RT results if 2nd NB lines are injecting*



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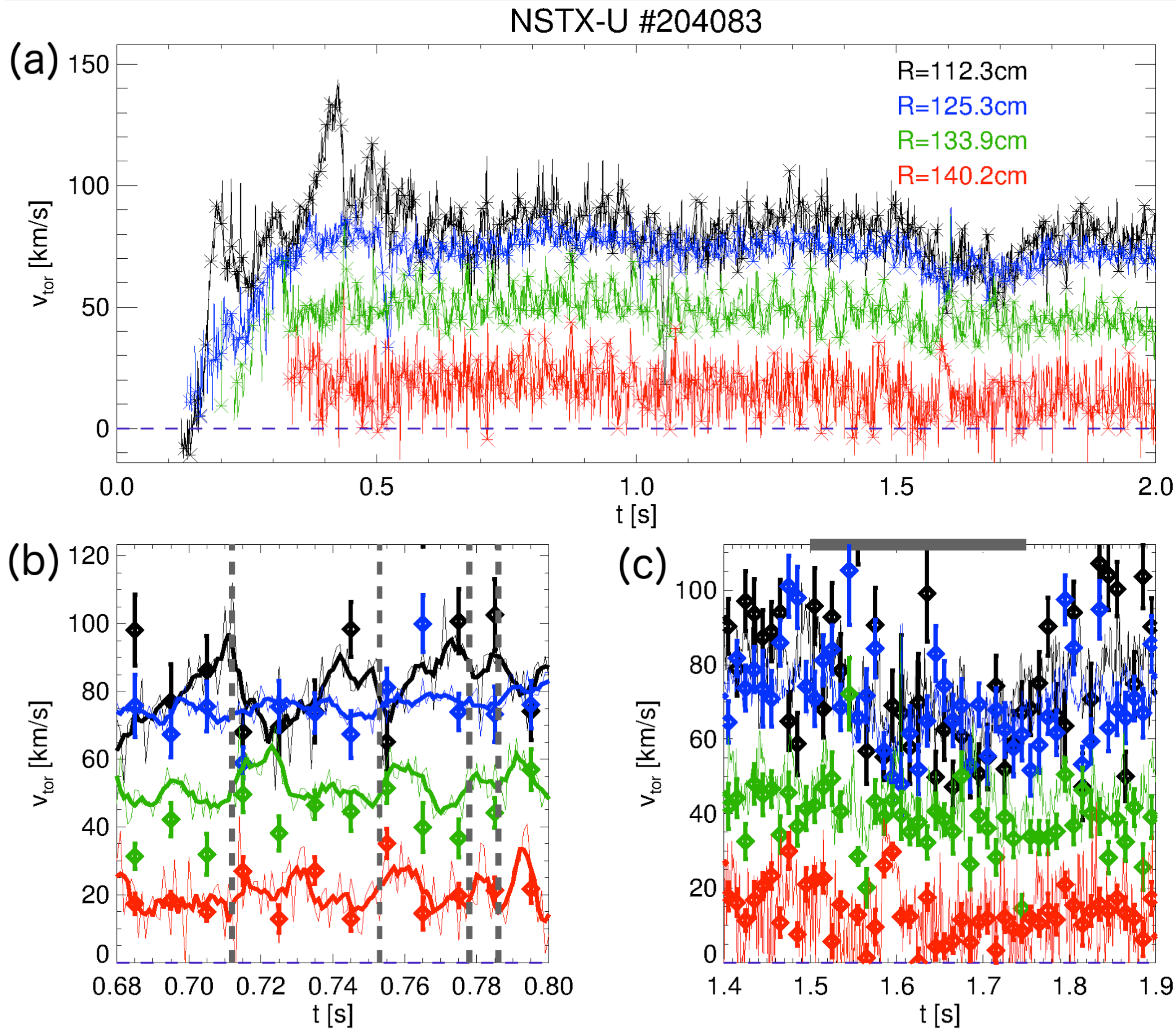
Sawteeth redistribute momentum, core v_ϕ decreases by ~20%

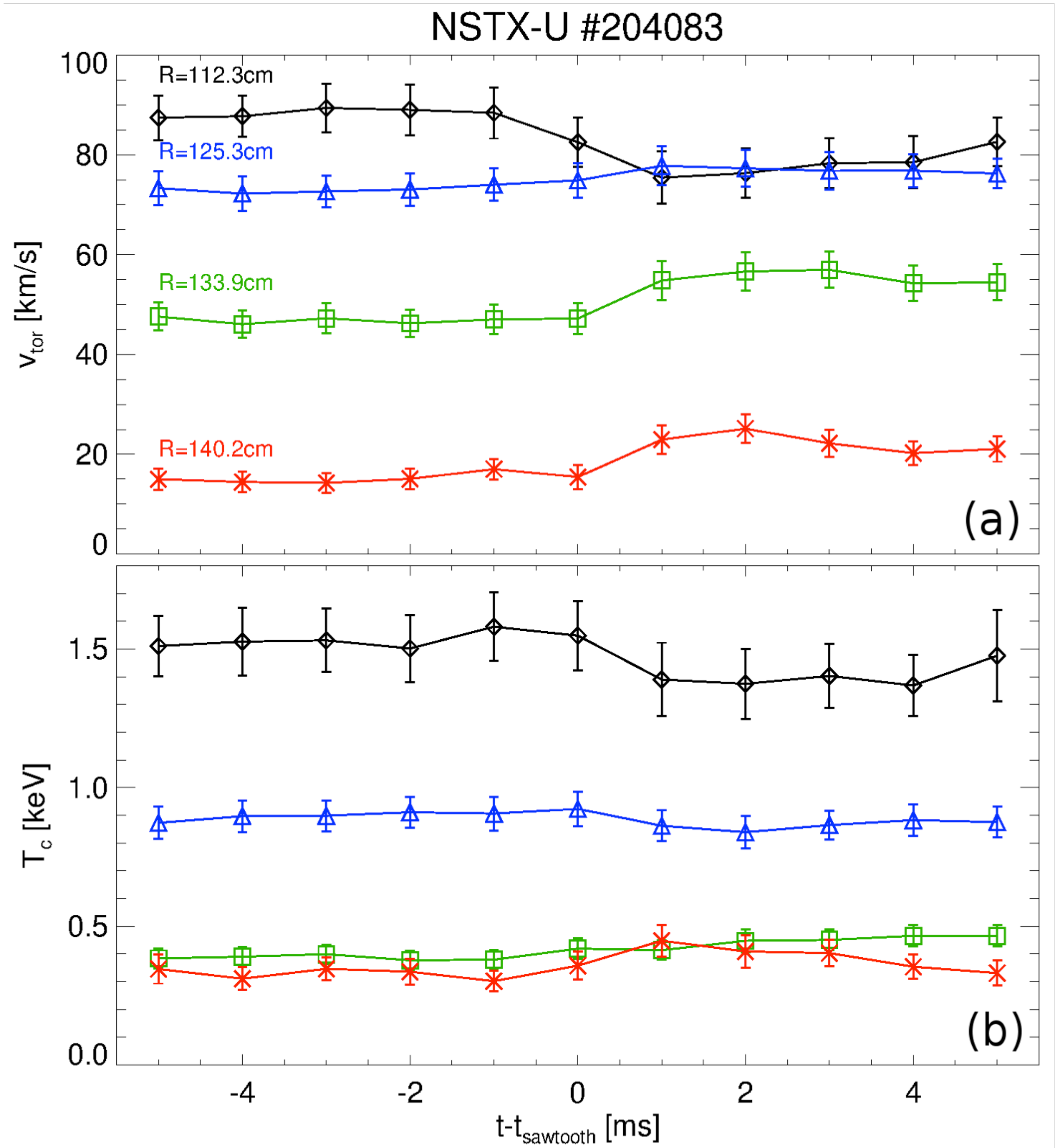
L-mode, P_{NB}~1MW

a) Sawteeth seen after t=0.5s
b) Crashes visible on $v_\phi(0)$, anti-correlate with increased v_ϕ at R>130cm
c) Large RMP pulse at 1.5s captured by RTV, CHERS

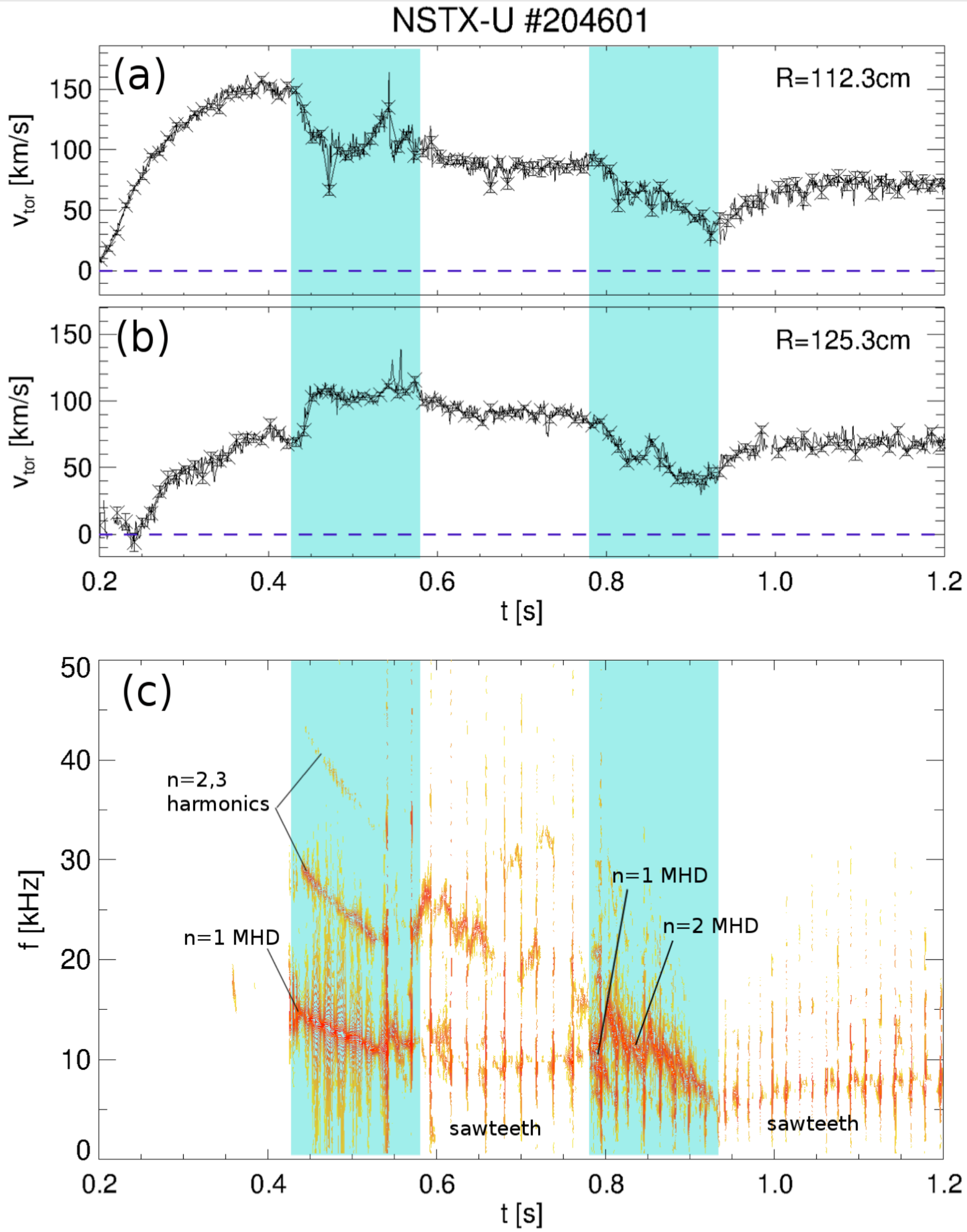


High sampling rate enables Conditional Averaging of sawteeth effects

- Conditional sampling of data at f_{samp}=1kHz
- Clear drop in core rotation, T_i
  - Core v_ϕ drops by ~20% over 2ms
- Estimated inv. radius is R~125cm
- Data suggest different dynamics for v_ϕ, T_i



MHD, sawteeth can compete in v_ϕ redistribution; different time scales, high f_{samp} enables separation

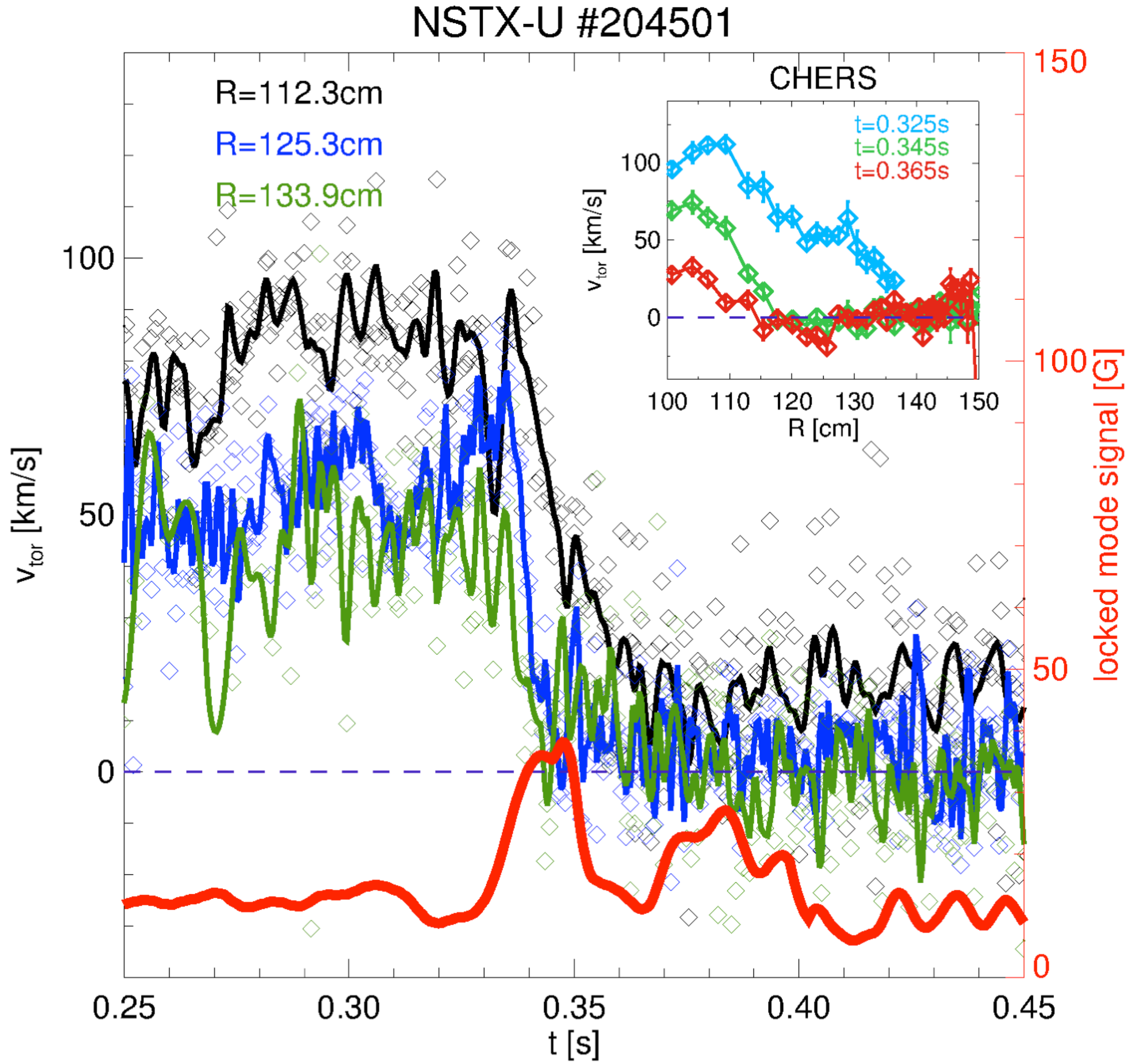


- Complex scenario
  - MHD n=1,2 modes act on ~10ms time scale
  - Sawteeth act on ~1ms time scale
- High f_{samp} of RTV allows to differentiate time scales
- Complements high spatial resolution CHERS profiles

Mode locking and associated fast dynamic clearly observed on RTV data

L-mode, P_{NB}~1.1MW

- Mode grows after t~0.33s, then locks over 10ms
- First, fast response observed outside mid-radius
  - Then propagates to the core
- CHERS provides full profiles pre/post locking (inset)



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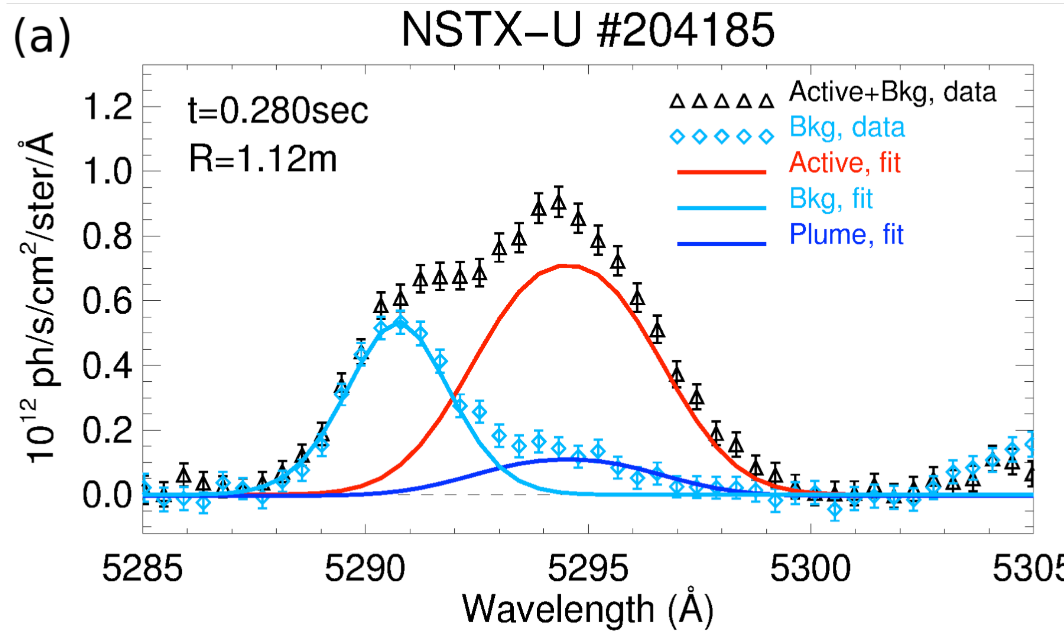
Summary & outlook

- First RTV data from NSTX-U confirm achievement of design goals
- System is ready to support development & testing of real-time v_ϕ control on NSTX-U
- Much more physics insight can be gathered from post-discharge analysis
  - E.g. effects of RMPs, MHD, ELMs, pellets/granules on v_ϕ, T_i, n_C
  - Complements high spatial resolution of CHERS with sub-millisecond time resolution (at 4 radii)
- Post-discharge automatic analysis tools implemented for routine operations
  - Ask MP to get access to the data (MDSplus nodes & IDL scripts)

Backup

Injection from second NB line compromises RTV (and CHERS) measurements

- Beam turn-off provides estimate of 2nd NBI contamination
- (a) only NB1 sources ON
- (b) NB1 + NB2 ON
  - Assume NB1 emission is unchanged from (a)
  - Subtract Active, Bkg from (a) to infer contamination from NB2
  - Signal from NB2 comparable to Active, Bkg
  - Spectrum is distorted
    - Superposition of active, background & plume from both NB lines
  - Cannot resolve lines (especially in real time)



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