Recent physics investigations at ASDEX Upgrade using TRANSP

G. Tardini, L. Casali, B. Geiger, D. Rittich, J. Rasmussen[1], P. Schneider, M. Weiland and the ASDEX Upgrade Team

Institut für Plasmaphysik, Garching, Germany
[1]Technical University of Denmark, Department of Physics, 2800 Kgs. Lyngby, Denmark

TRANSP User Group Meeting, Princeton, March 23-24th 2015

Overview

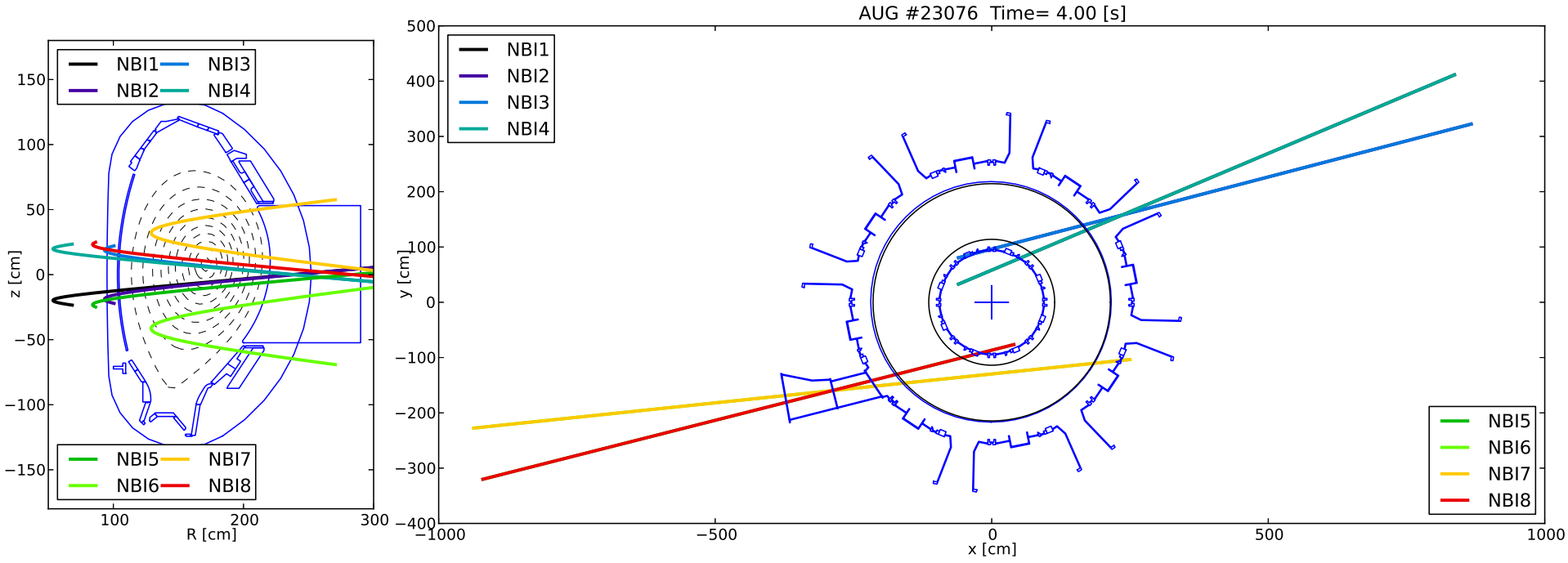
Power balance analysis

- Core transport in N_2 seeded discharges

Diagnostic simulation using TRANSP's FBM output (fast ions)

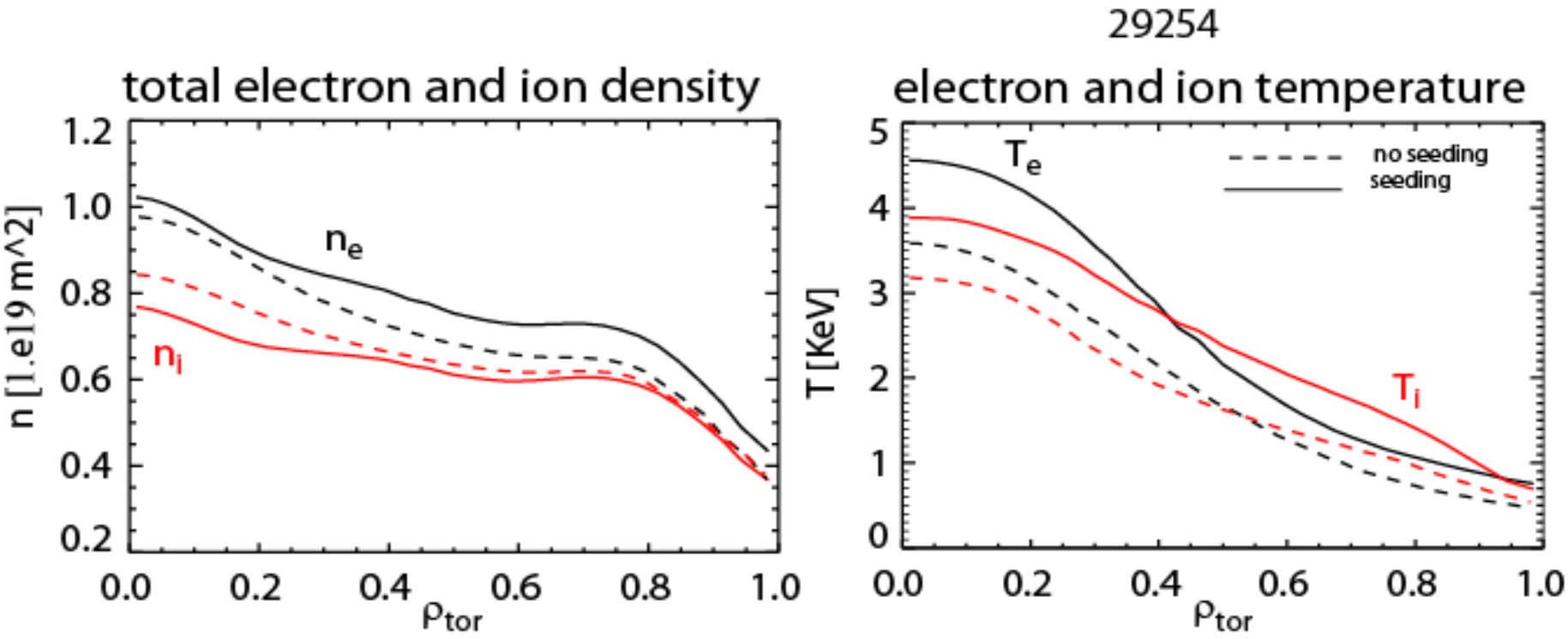
- Simulation of line-of-sight neutron spectra
- Collective Thomson Scattering modelling
- Modelling FIDA spectra and profiles:
  - MHD bursts: e.g. sawtooth crash
  - D-acceleration by ICRF
- MSE and neutral beam current drive

ASDEX upgrade, NBI system



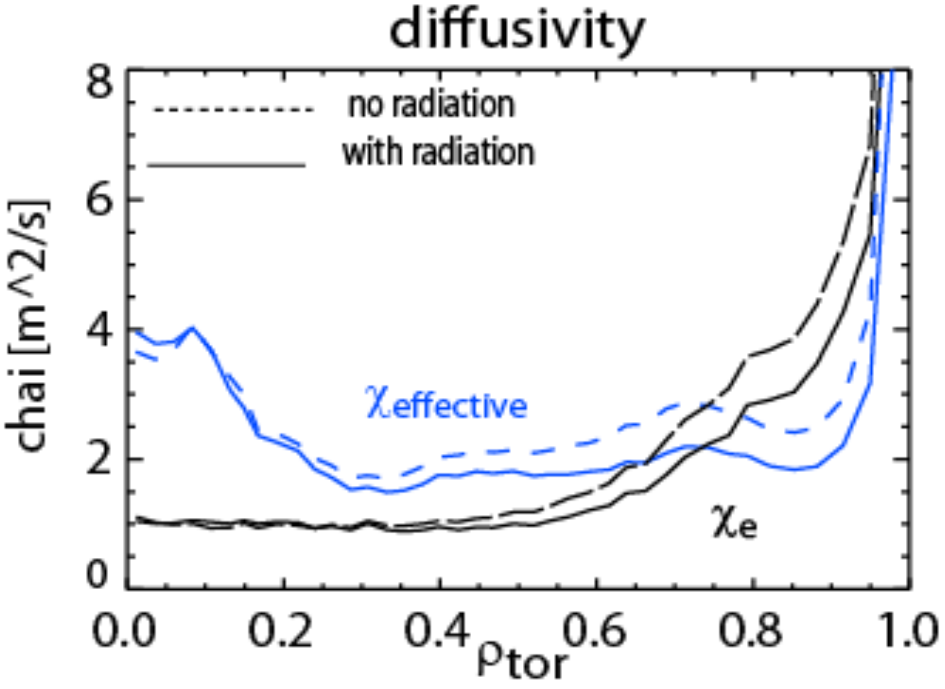
- E_{NBI} = 60-93 keV, plus 1/2, 1/3 energy
- Off-axis tangential sources NBI #6, #7

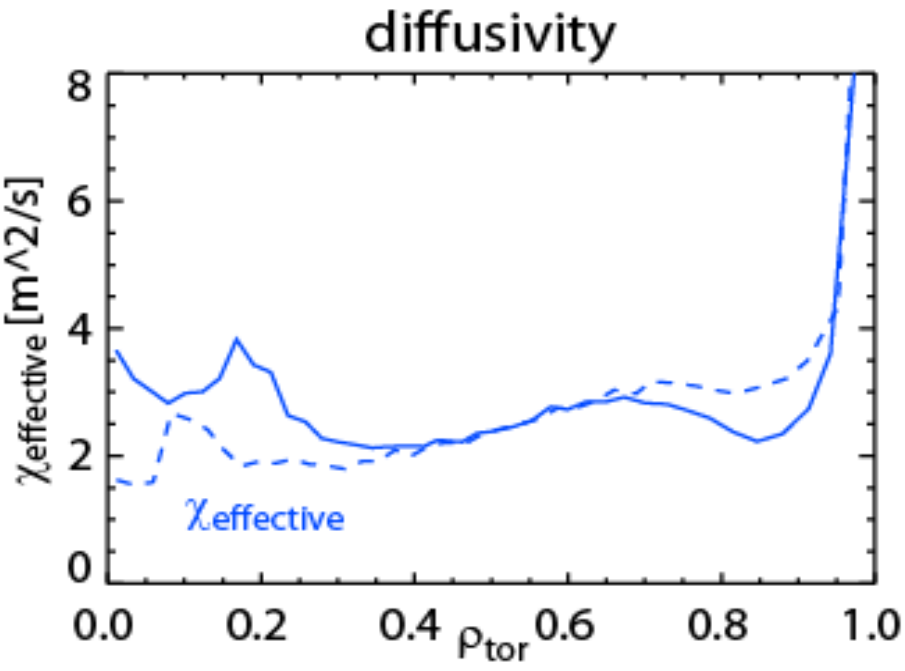
Confinement in N_2 seeded H-modes



- Global confinement increases significantly (10-30%)
- Higher pedestal top values of n_e, T_e and T_i with N_2 seeding
- Different gradients, radiation profiles, (slightly) NBI deposition

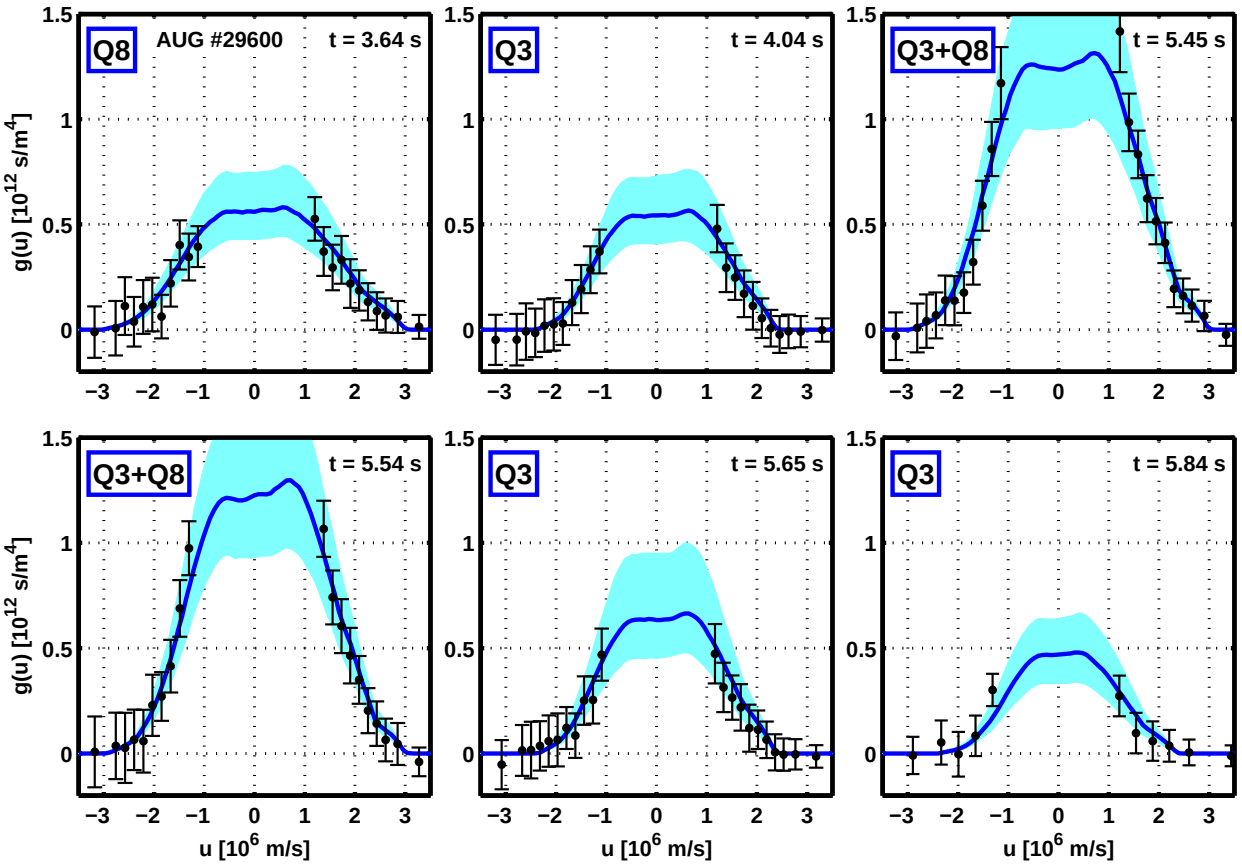
Confinement in N_2 seeded H-modes





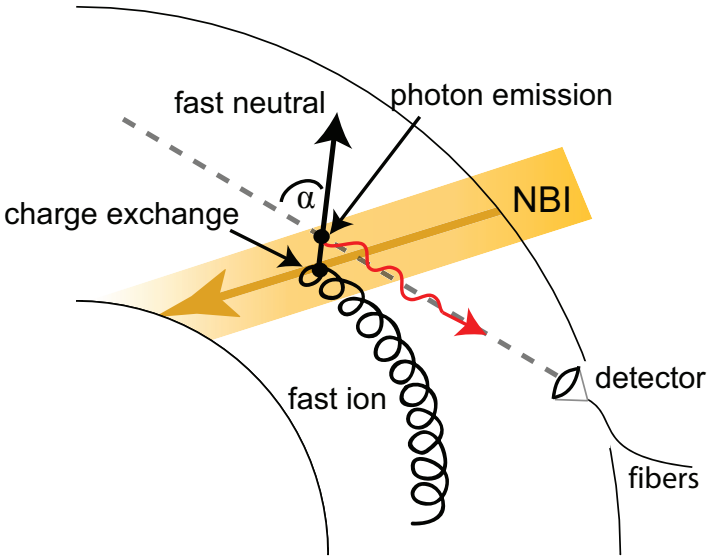
- Input radiated power:
  non-coronal model using atomic data + comparison with bolometer.
  Almost no difference in core power balance compared to zero radiation.
  Radiation affects only the plasma edge.
- χ almost unchanged before and after N_2 seeding

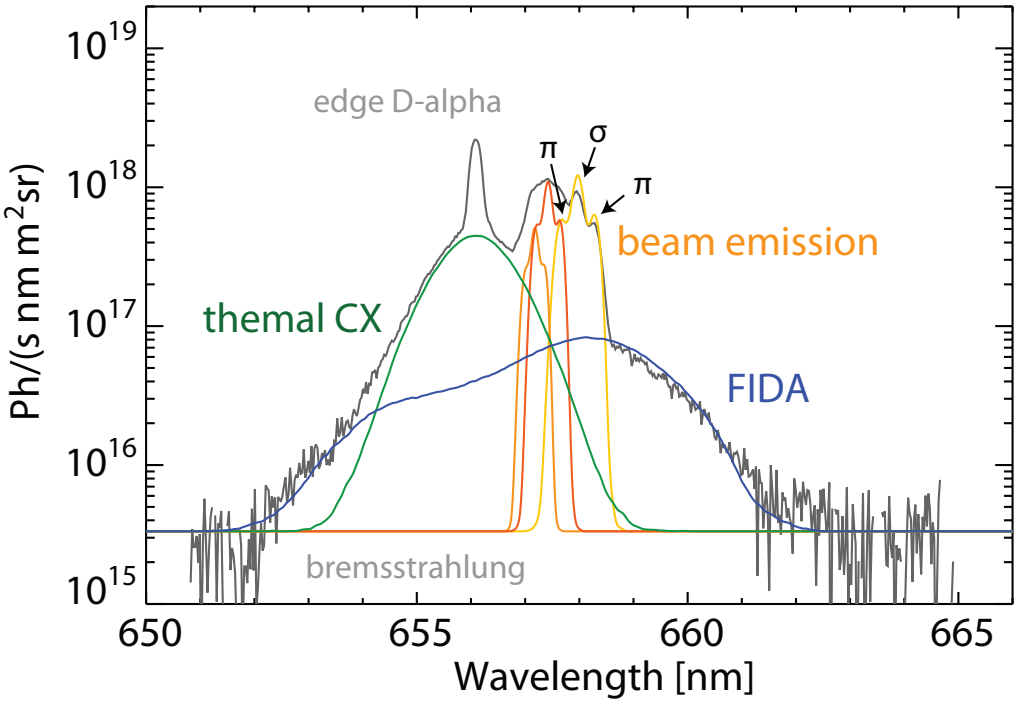
Synthetic Collective Thomason Scattering diagnostic



- FBM projection on $\overrightarrow{v}$, exp vs TRANSP (blue)
- Good match with different NBI sources (voltage), kinetic profiles
- Cyan region: confidence interval (10 % in n_e, ...)

Fast-Ion D-Alpha (FIDA) diagnostic

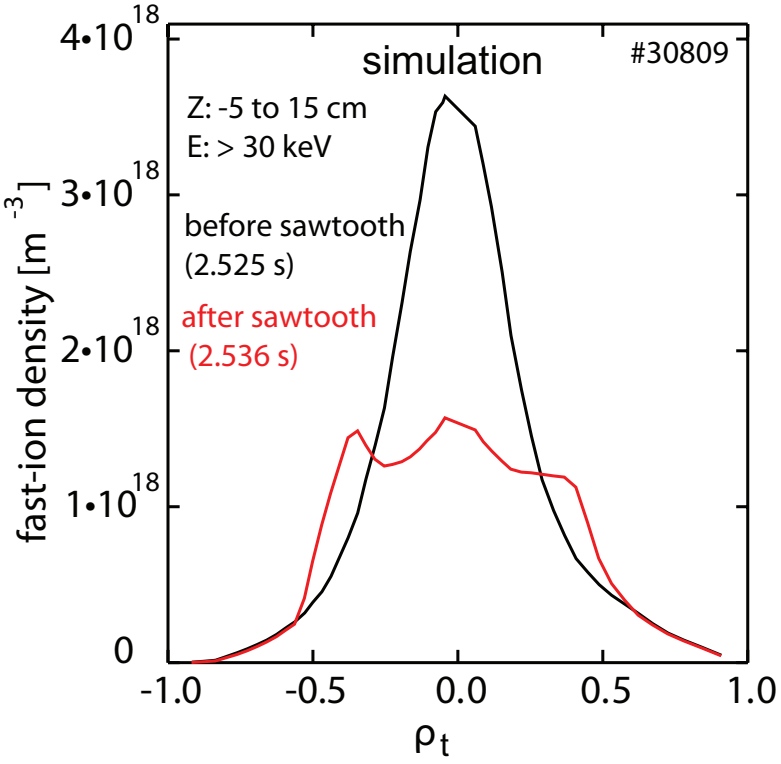


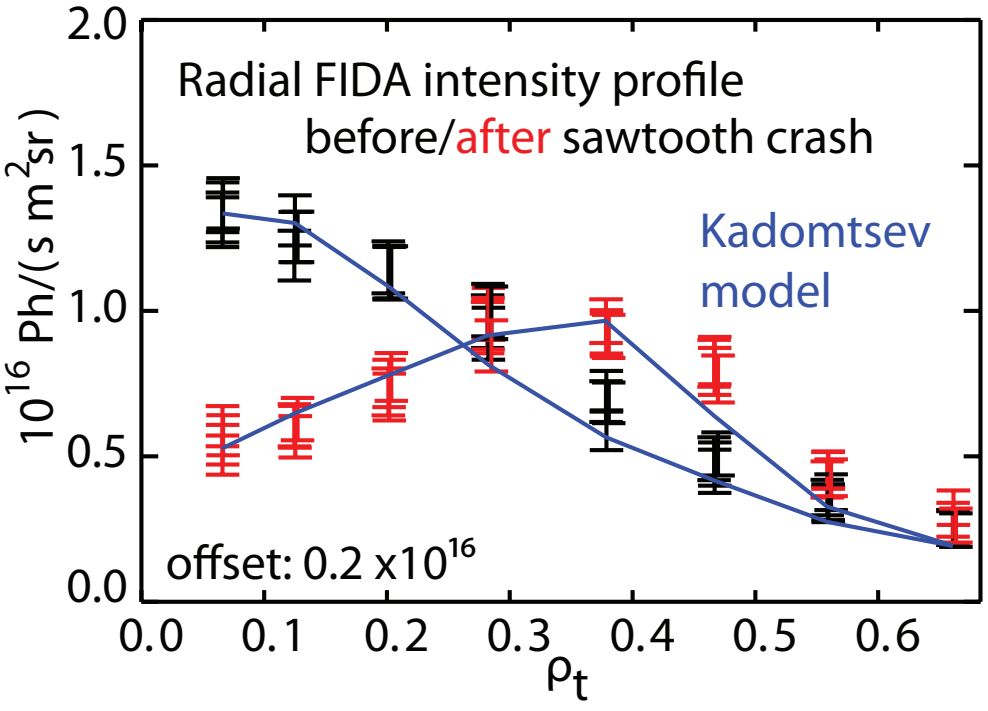


- CXRS technique applied on fast ions (Doppler shifted Balmer Alpha radiation ($\lambda_0 = 656.1$ nm)
- Forward modelling to interprete the data: TRANSP (FBM) + FIDASIM (synthetic spectra) [Heidbrink, Commun. Comput. Phys.2011]

Geiger RSI 13

Fast-ion bursts due to sawtooth crashes



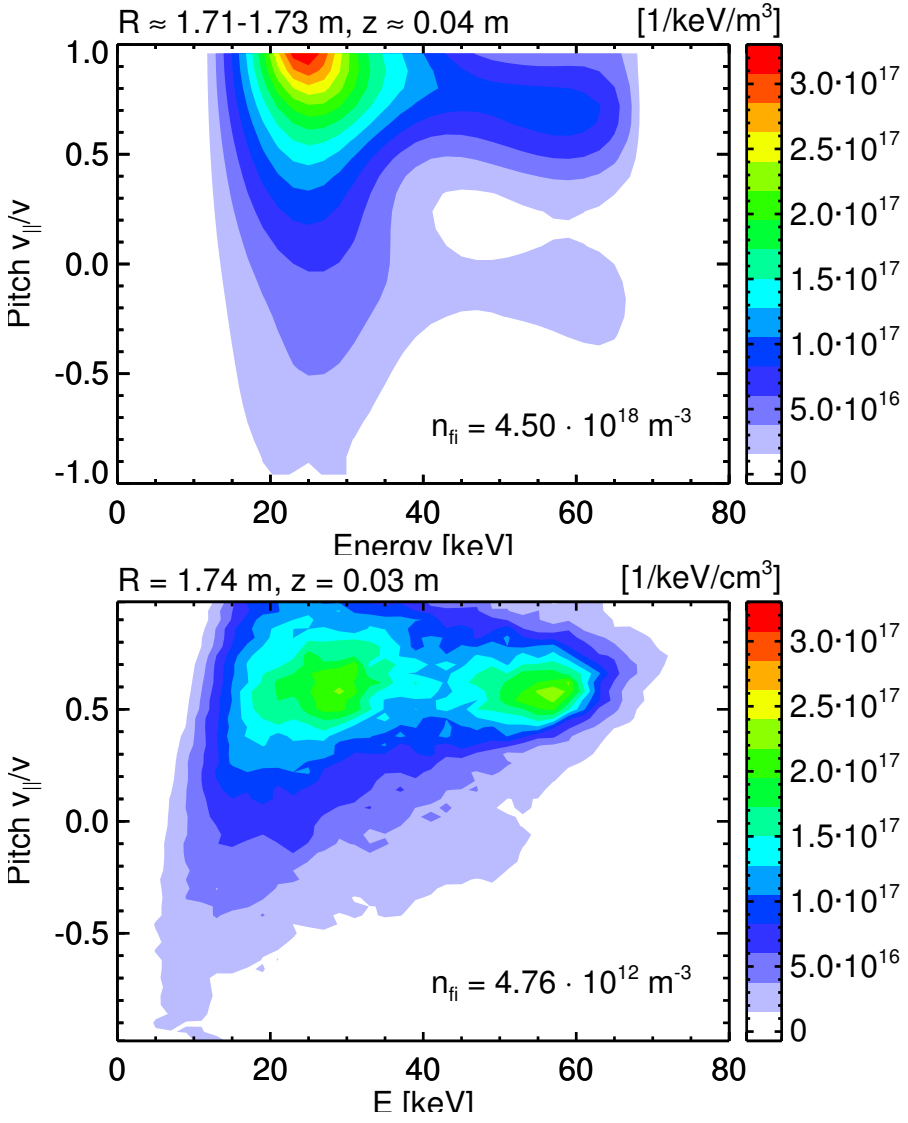


- TRANSP-Kadomtsev: sawtooth crash redistributes $\sim$ 50 % of central f.i. population
- Good TRANSP/FIDASIM prediction of FIDA fast-ions above 30 keV

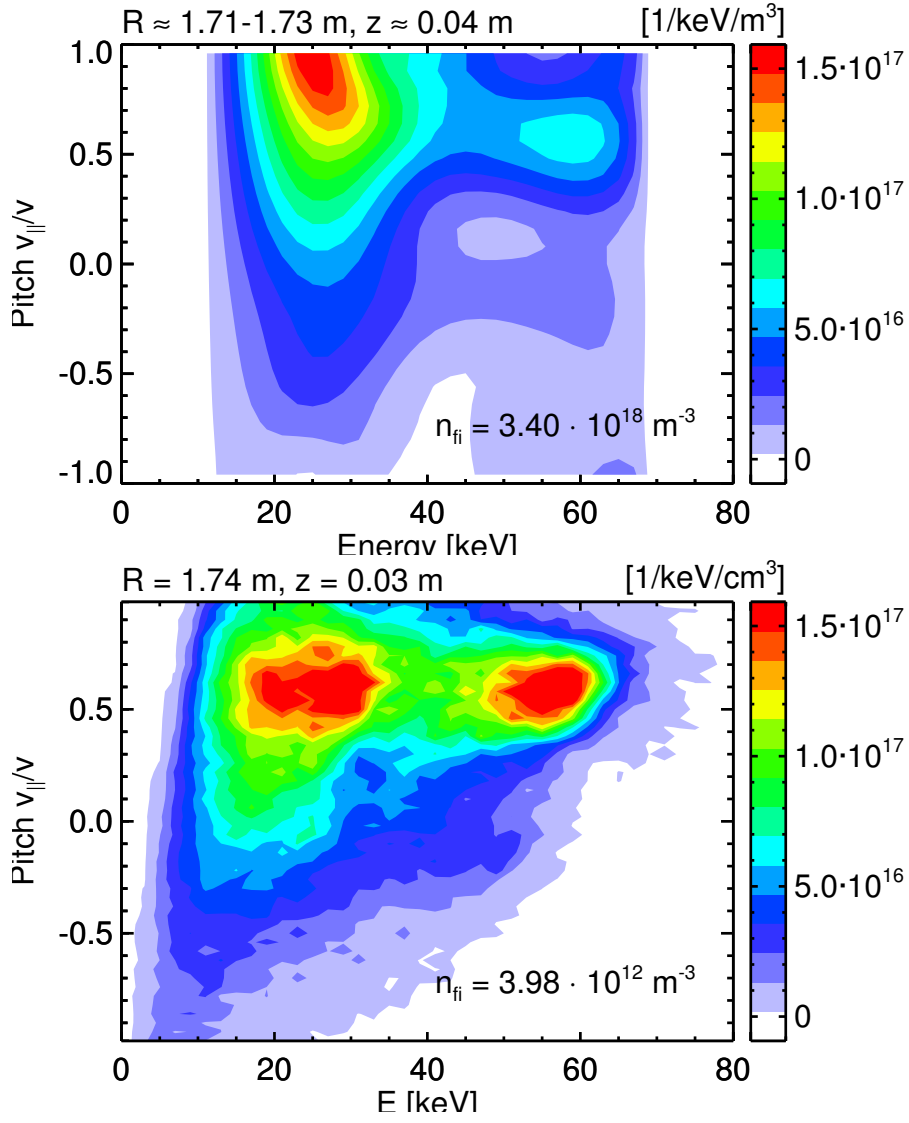
Geiger PPCF 15

FBM tomography with 5 FIDA views

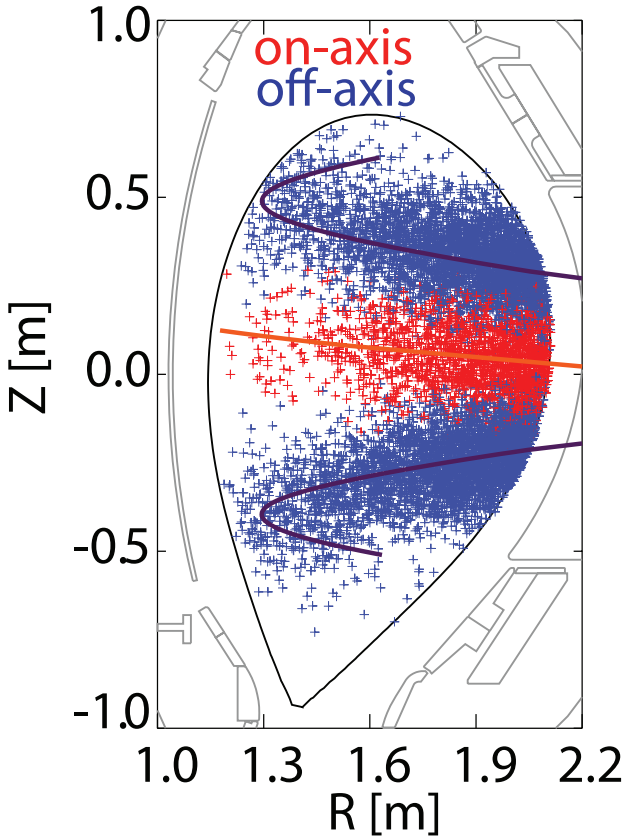
Before sawtooth crash:

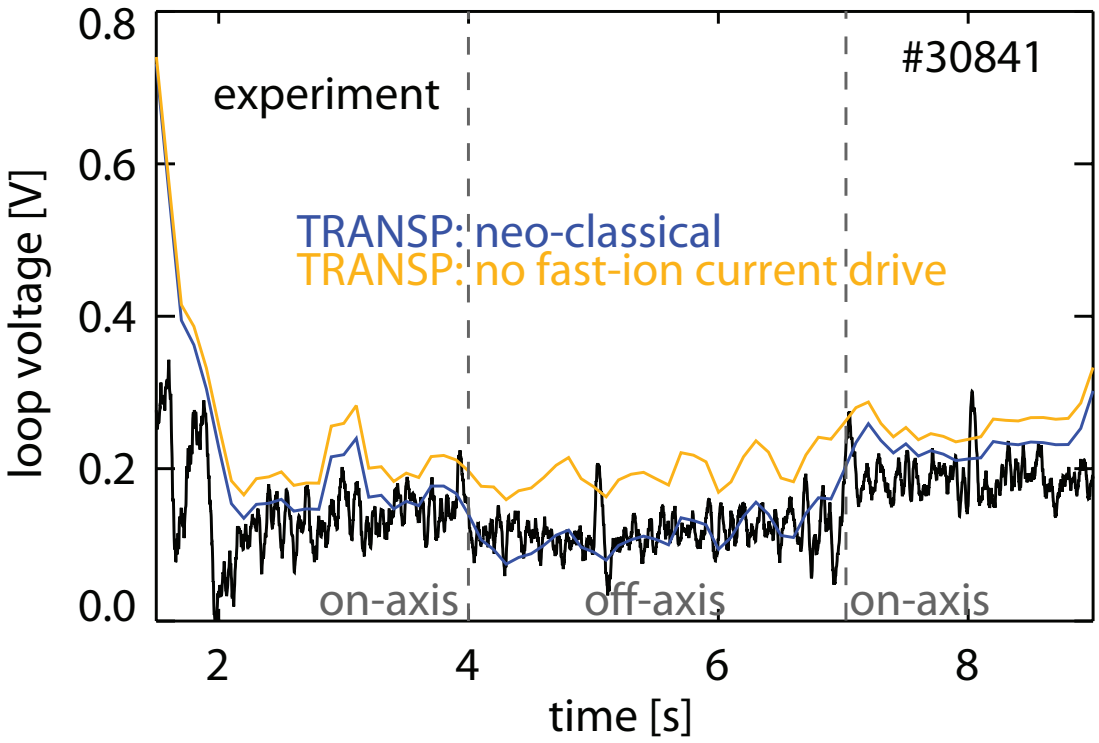


After sawtooth crash:



Off-axis Neutral Beam current drive



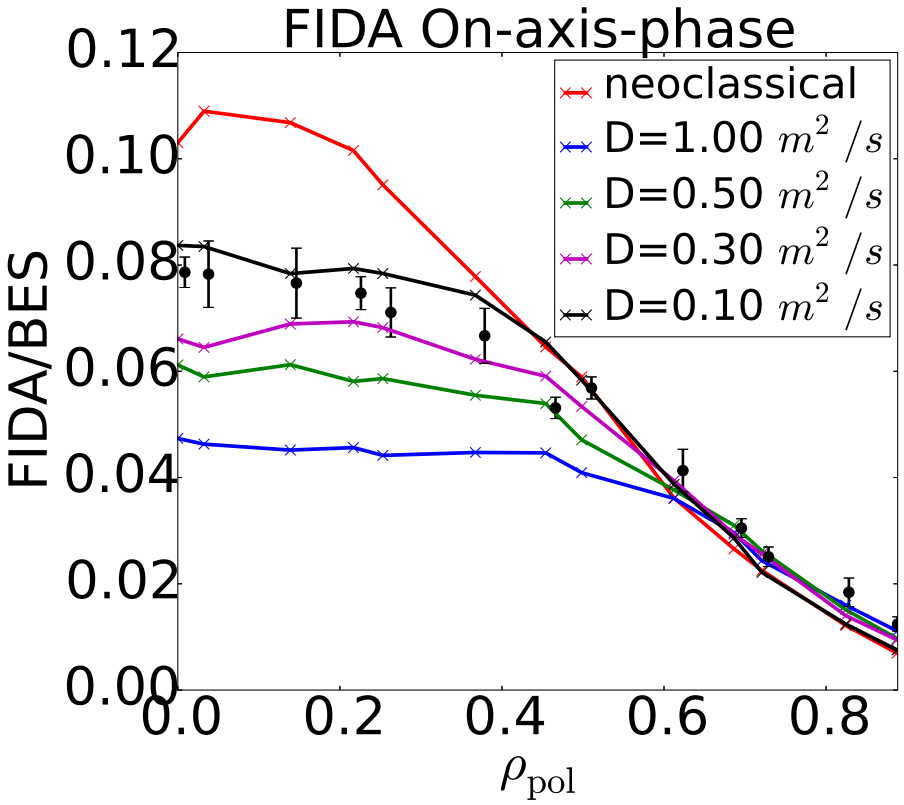


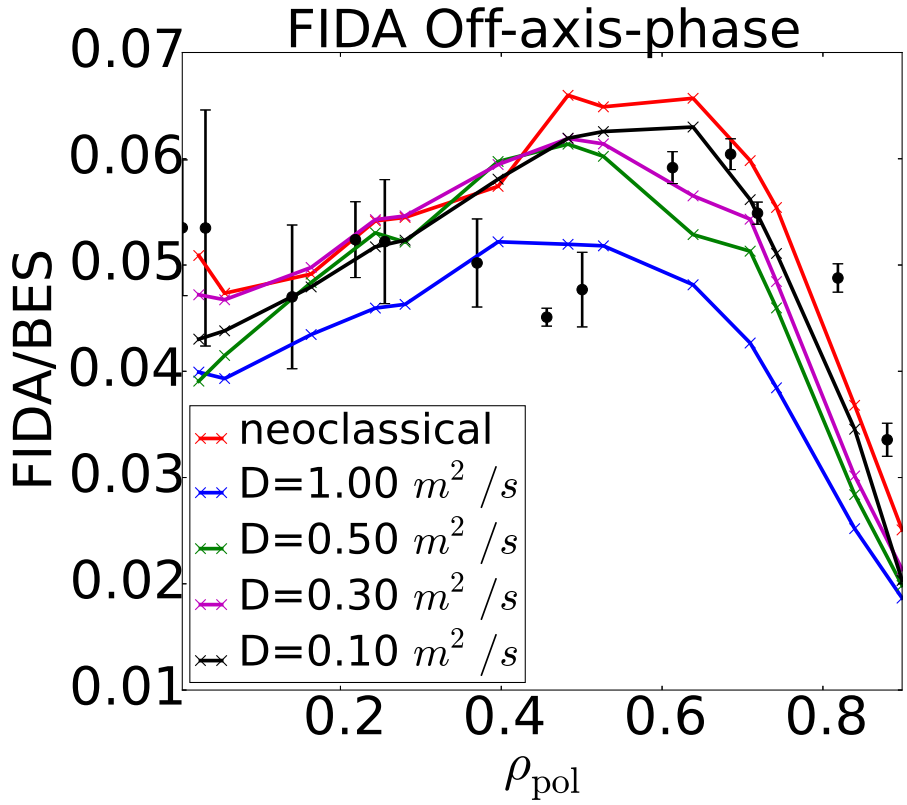
- Analysis of NBCD experiments: on-axis beams replaced by off-axis
- TRANSP U_{loop} (noe-classical f.i.) agrees with exp. data

Geiger PPCF 15

Off-axis Neutral Beam current drive

31453

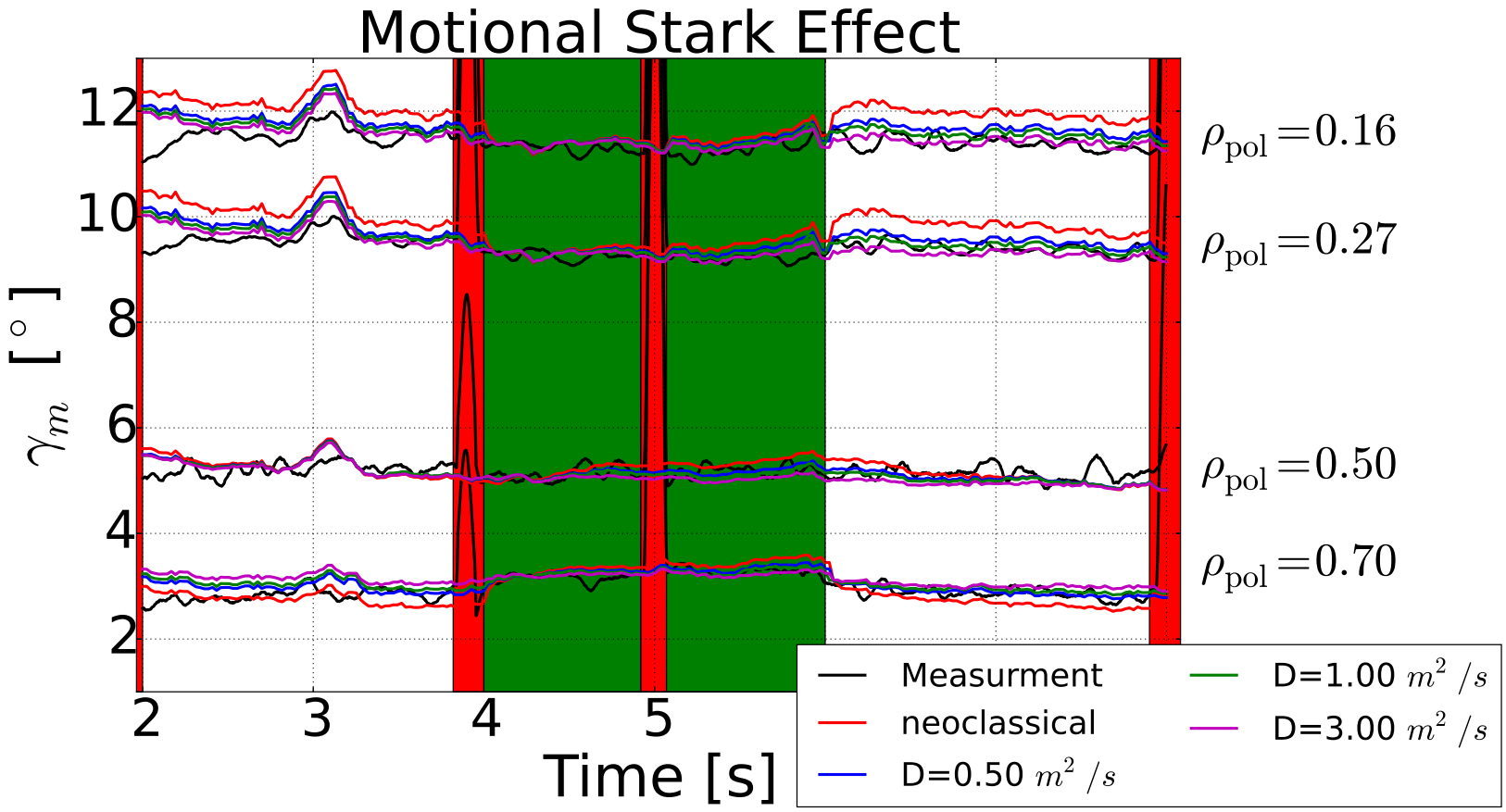




- FIDA observes clearly off-axis peaked f.i. density
- Light anomalous diffusion: best fit $D_{fast} = 0.1$ m^2/s

Rittich DPG 15

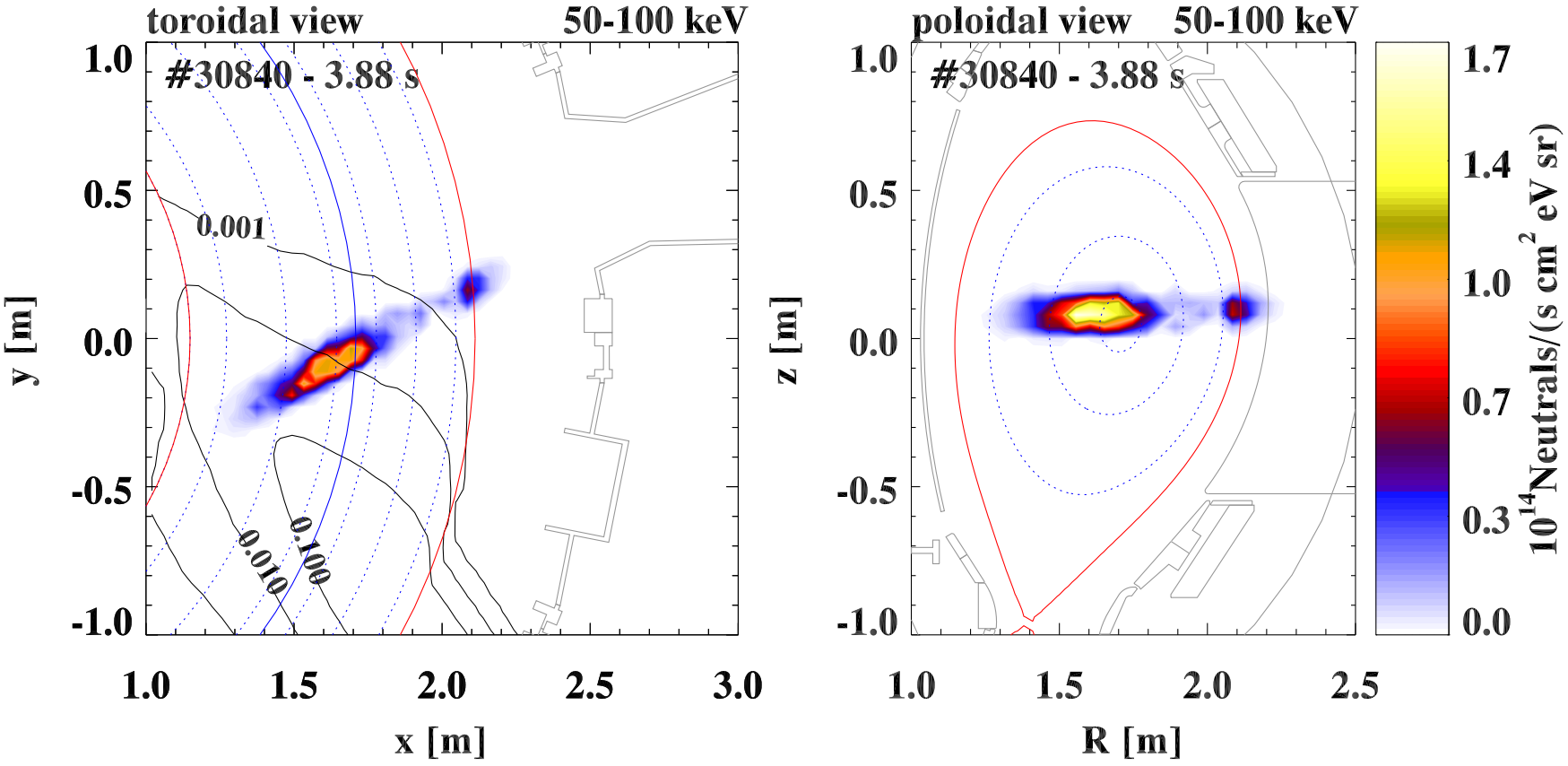
Off-axis Neutral Beam current drive



- MSE: $D_{fast} = 1\ m^2/s$ (inconsistent with FIDA)
- Polarimetry (not shown): TRANSP equilibrium used. No clear evidence

Rittich DPG 15

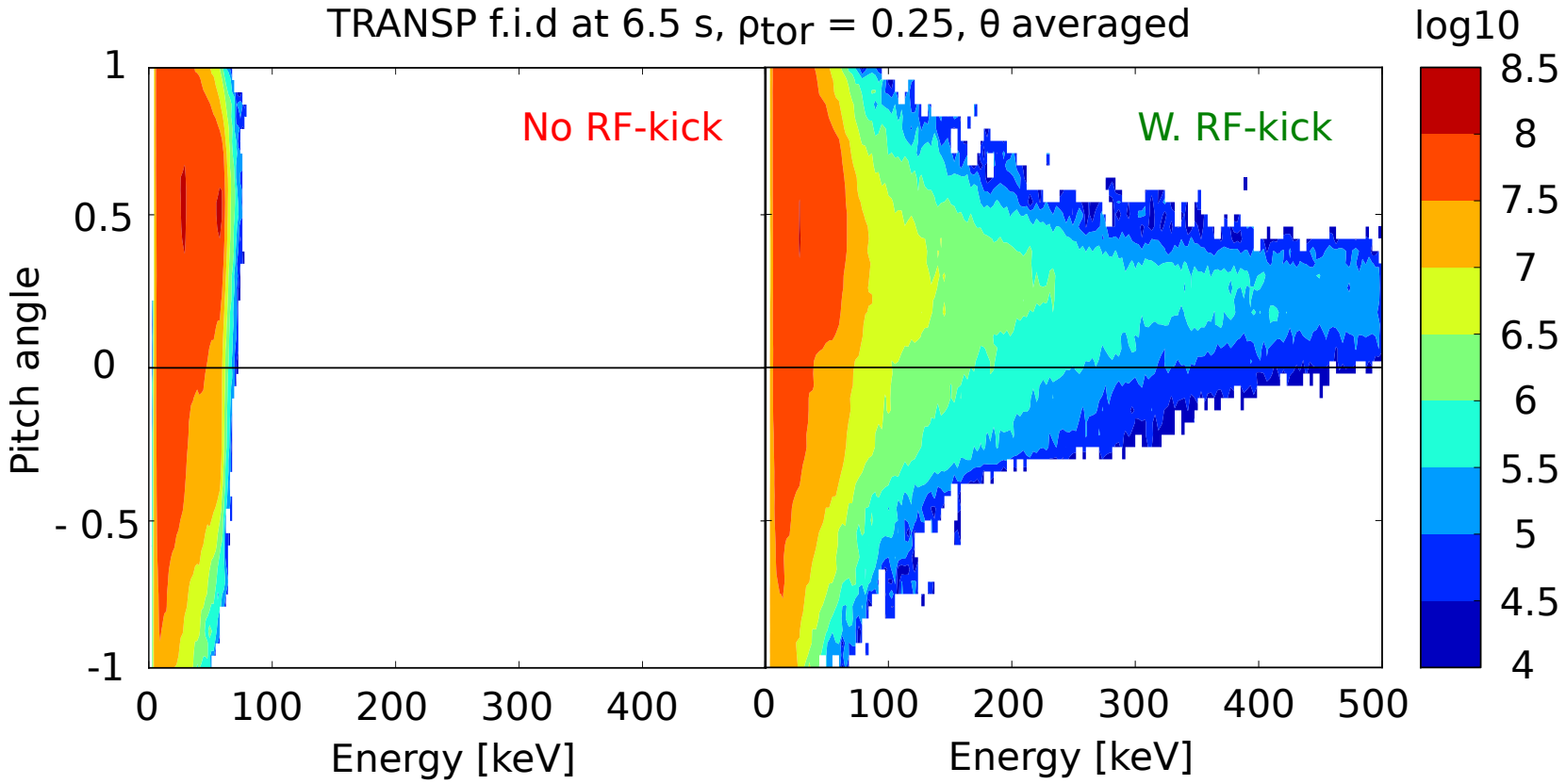
Synthetic Neutral Particle Analyser diag



- FBM used as input for synthetic NPA diagnostic in FIDASIM
- Output: energy, pitch and spatially resolved neutral fluxes separated in active and passive component

Schneider ECPD conference 15 (soon)

FBM for 2nd harmonic ICRH on NBI-D



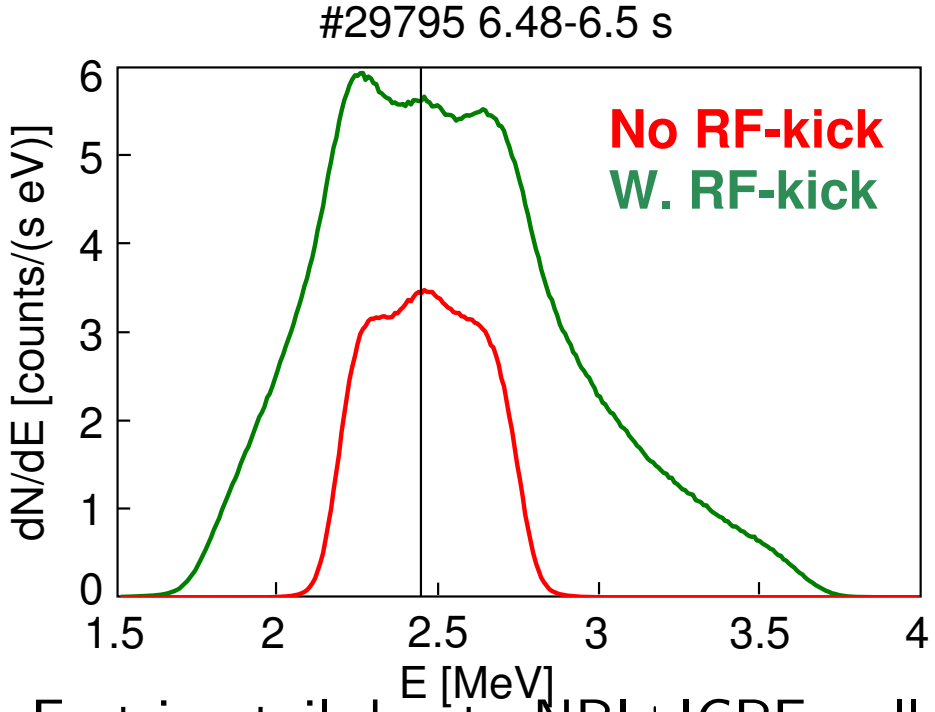
With RF-kick operator:

- More fast ions overall
- Significant amount of fast ions up to several 100 keV's
- ICRF accelerates $v_\perp$ (low pitch angle)

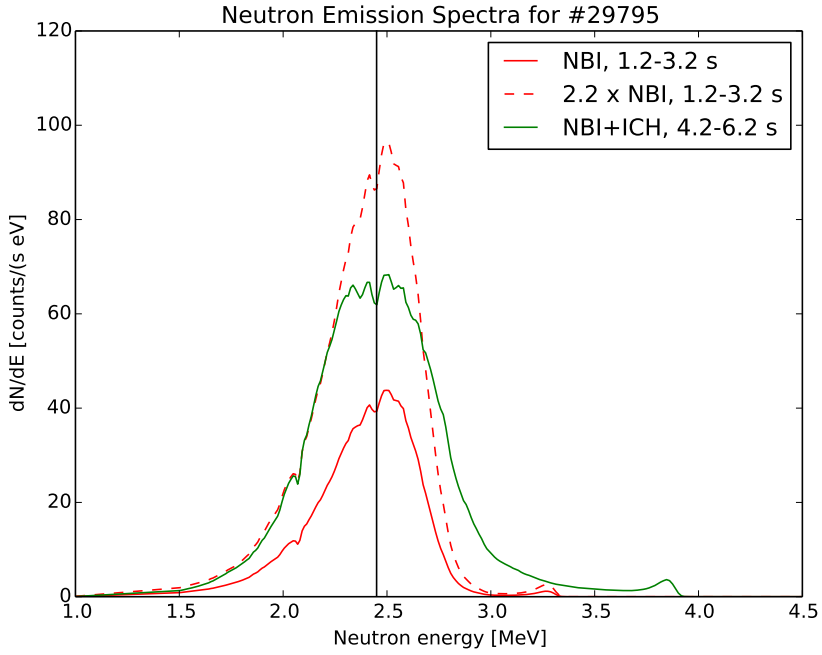
Tardini EPS 14

Line-of-sight simulation of neutron spectra

FBM → GENESIS [Nocente NF 11]



Exp unfolded with MAXED [Reginatto RSI 08]



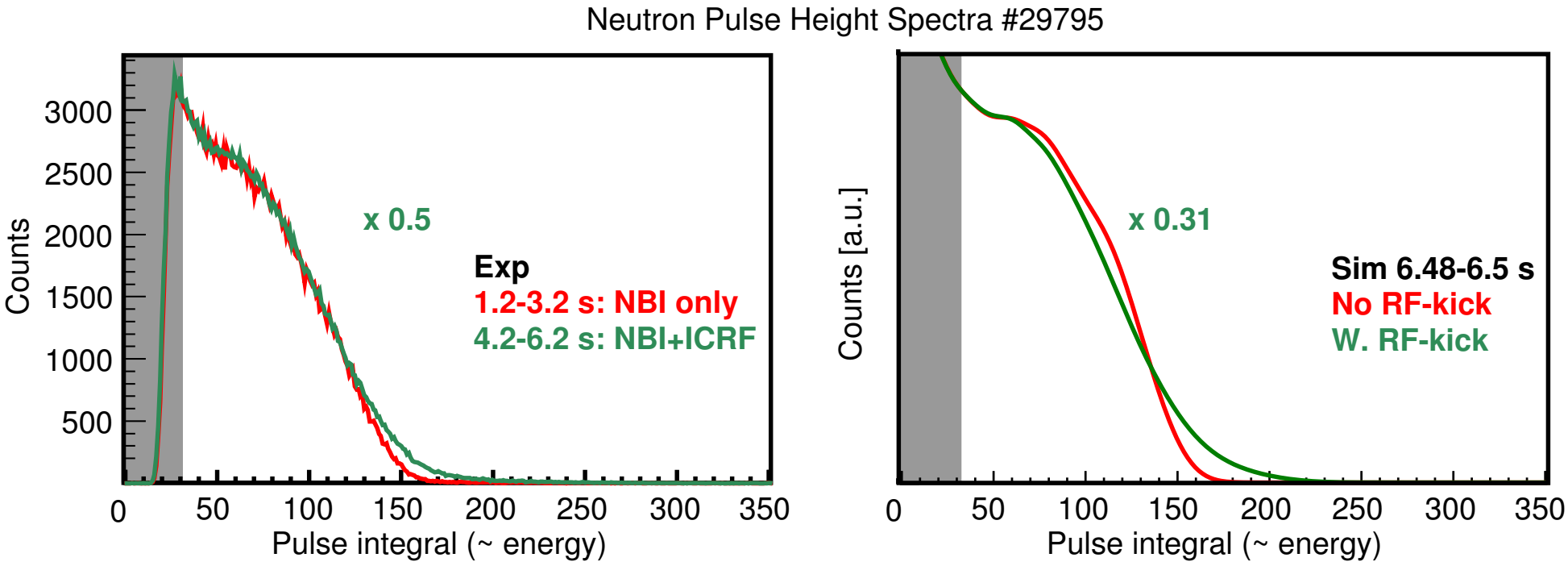
- Fast ion tail due to NBI+ICRF well visible
- Half Width $\approx \sqrt{(E_{fus} E_{fast})} \approx 500$ keV for $E_{fast} = 93$ keV, ≈ 1 MeV for $E_{fast} = 400$ keV
- Broadening and total neutrons: slightly overpredicted

Tardini EPS 15 (soon)

Pulse height spectra

Exp pulse height spectrum

GENESIS spectrum folded with response matrix



- Simulation: good prediction of broadening, slightly overpredicted
- Total neutrons (multiplying factor): overpredicted

Tardini EPS 14

Interesting tools

Python-GUI-based I/O tools:

- fbm (viewing cdf output of FBM's)
- cdfplayer (viewing CDF output profiles and equilibrium)
- trgui (less exportable) $\sim$ xtranspin + scruncher

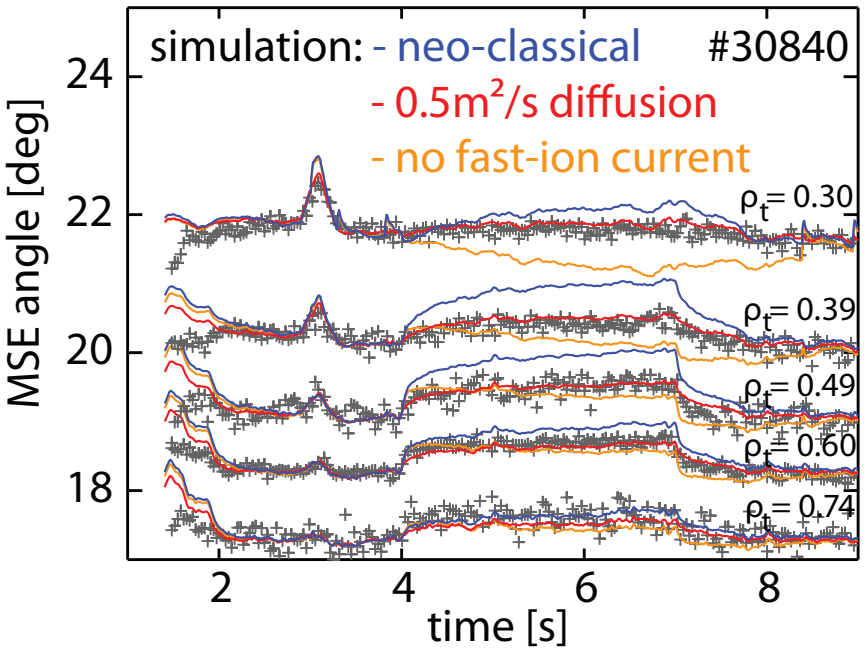
FBM input for synthetic fast ions diagnostics:

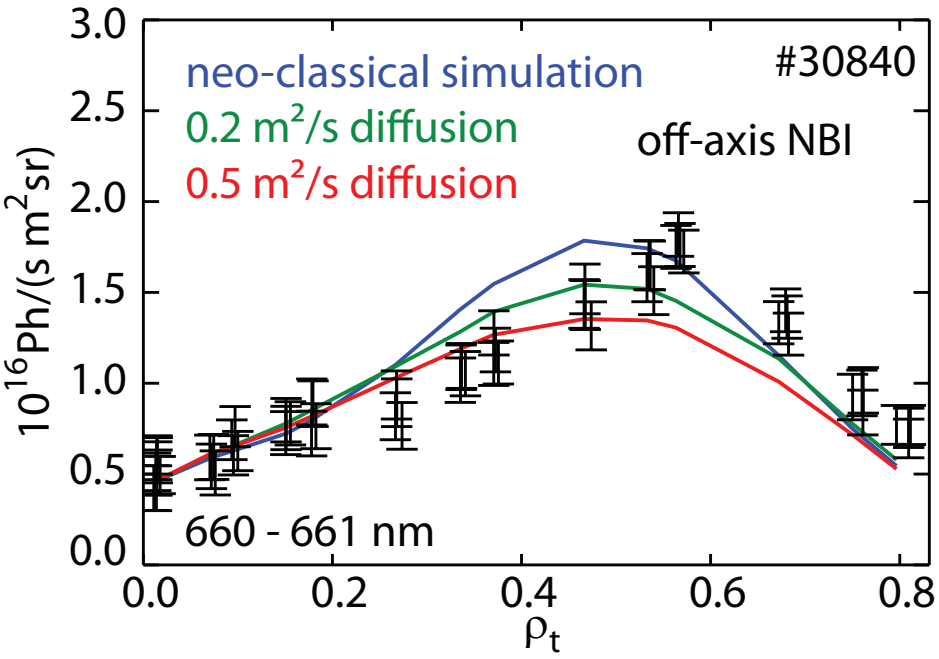
- CTS
- Interfaces to GENESIS and FIDASIM (FIDA, NPA, NESP)

Possible extensions/development

- TORBEAM in TRANSP (underway)
- Validation of RF-kick (comparison with TORIC+ssfpql underway)
- TORIC 6?
- Heat, torque and particle fluxes in standard NetCDF output. Wrote and shared some notes.
- No urgent need for having these synthetic diagnostics online (heavy computation and/or output file size), just offline coupling
- ADAS cross-sections for radiation (available); cooling factor for W (available); non-corona model for light impurities.

Off-axis Neutral Beam current drive



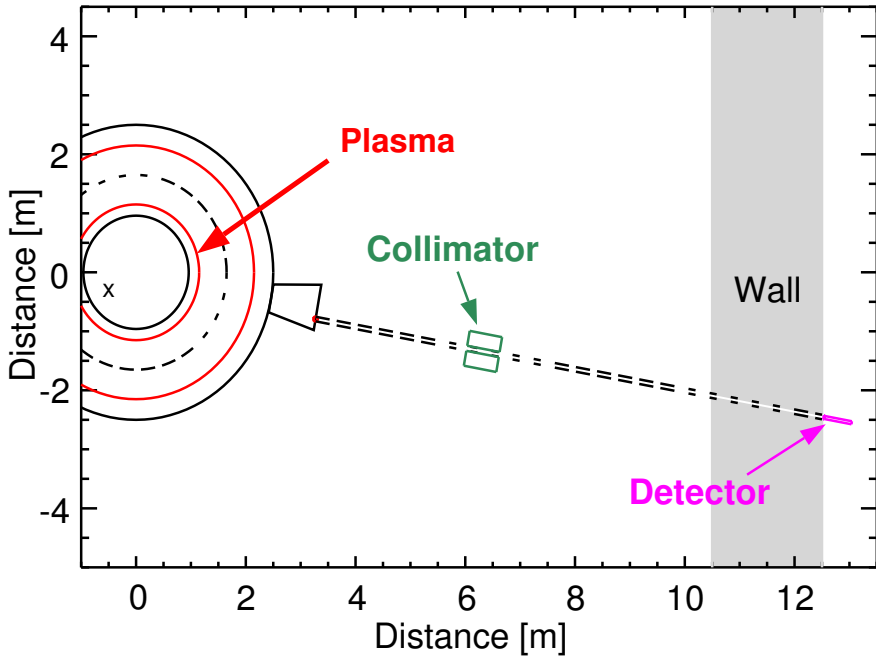


- MHD activity (kink mode?)
- No agreement for neo-classical, better with $D_{fi} = 0.5 m^2/s$
- FIDA profiles above 30 keV: need $D_{fi} \approx 0.2 - 0.5 m^2/s$

Geiger PPCF 15

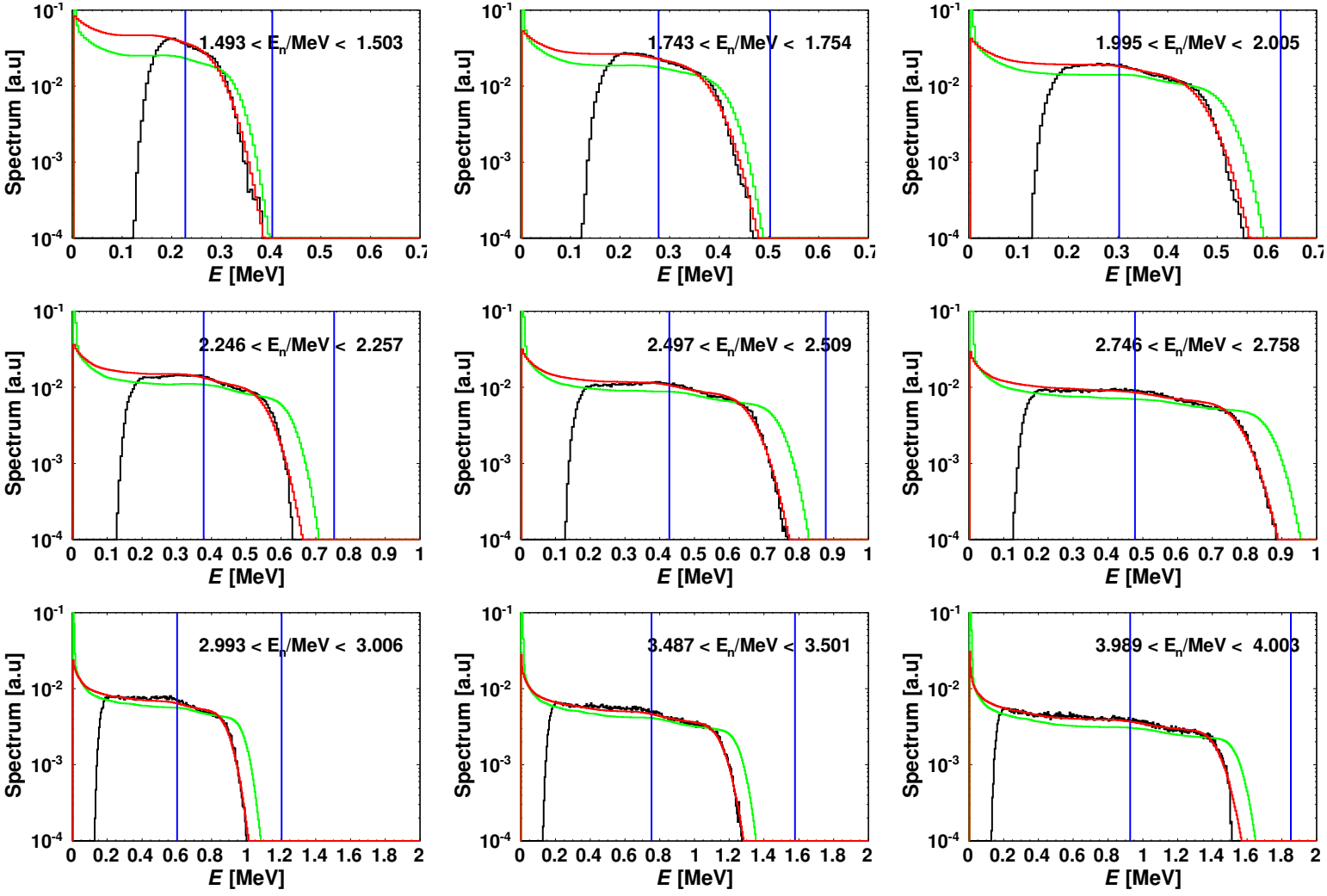
Compact Neutron Spectrometer at AUG

CNS location



- LOS: $\sim\perp$, 10 cm above equatorial plane ($\sim$ plasma center)
- $\sim$ 10 m from plasma, 2 m concrete for collimation and screening
- Pre-collimator: polyethylene in Al cube (60 cm) + 2 $\times$ 5cm lead (γ screening), hole ($\oslash$ 7.6 cm) along LOS
- BC501a liquid scintillator cell ($\oslash$ 50.8 $\times$ 50.8 mm) + PMT + reference LED (100 ns pulse, 1 kHz) for gain correction [Giacomelli RSI 11]

Detector's response for neutrons



Direct D heating: fast D acceleration

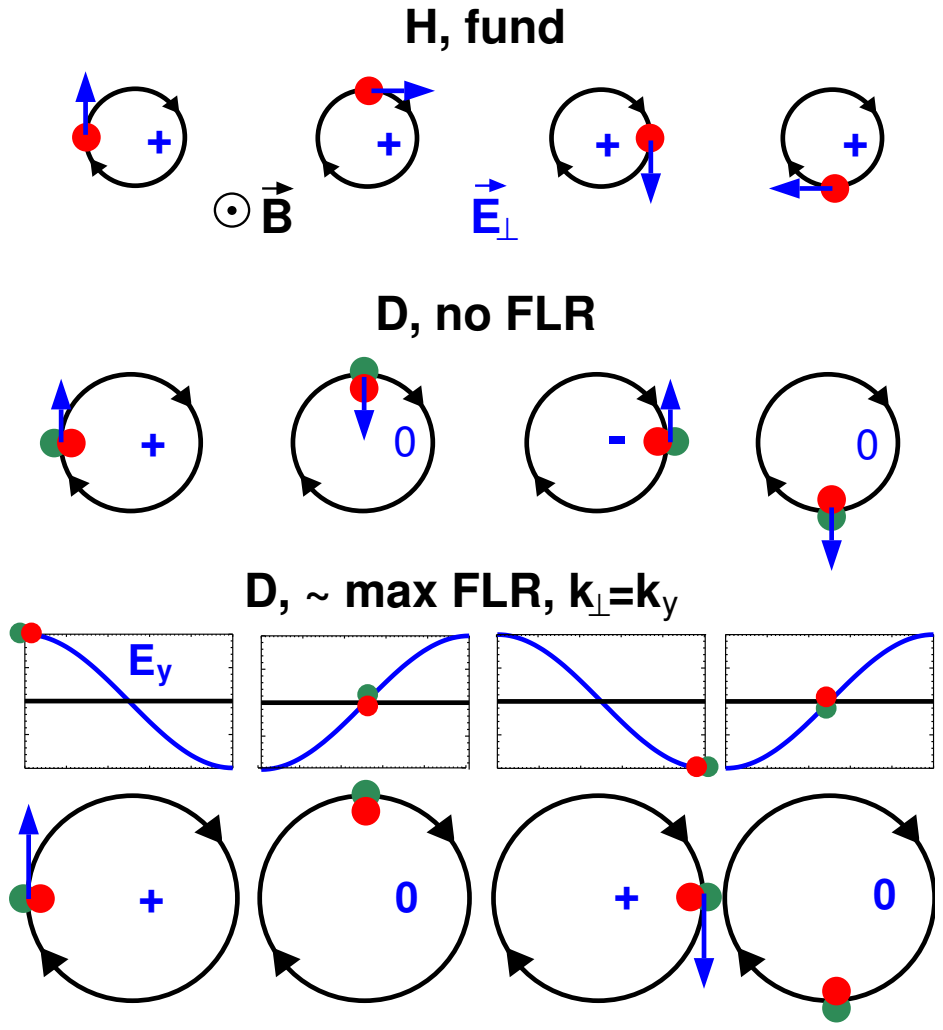
- ICRF wave circularly polarised

- H: $\omega_{ICRF} = \omega_{gyr,H}$
  $\overrightarrow{E}$ in phase with gyration
  $\Longrightarrow$ efficient acceleration

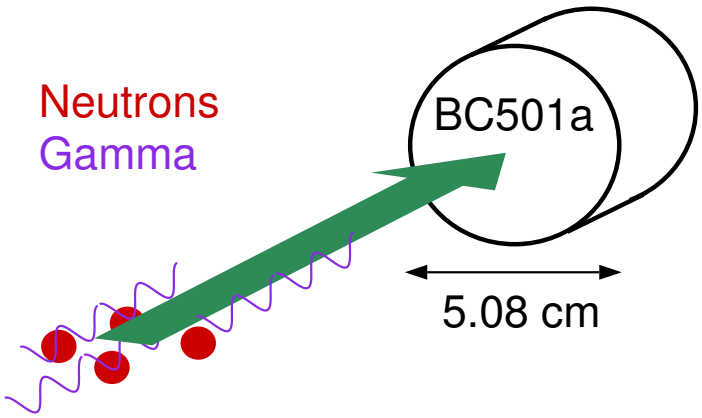
- D : $\omega_{ICRF} = 2\omega_{gyr,D}$
  - $\rho_L^D << \lambda_\perp \Longrightarrow$ no net acceleration

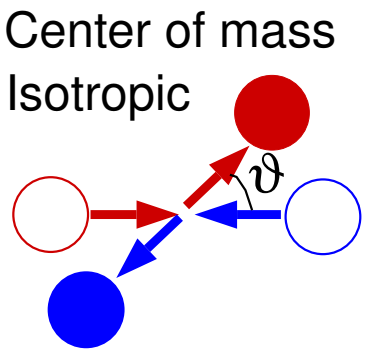
  - $\rho_L^D \sim \lambda_\perp$
    Max effect for $2\rho_L^D \approx \frac{\lambda_\perp}{2}$
    $\rho_L^D \approx 2$ cm (E=60 keV, B=2.1 T)
    $\lambda_\perp \approx 40$ cm

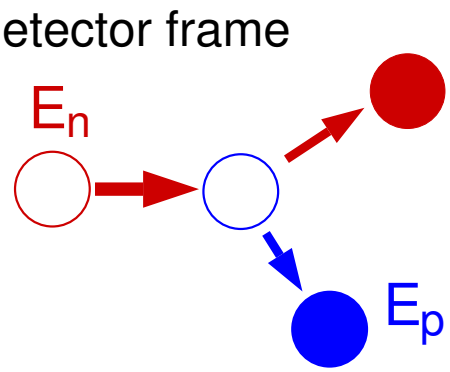
- Need favourable $\nabla F(v)$ for net effect on ion population



Measurement principle

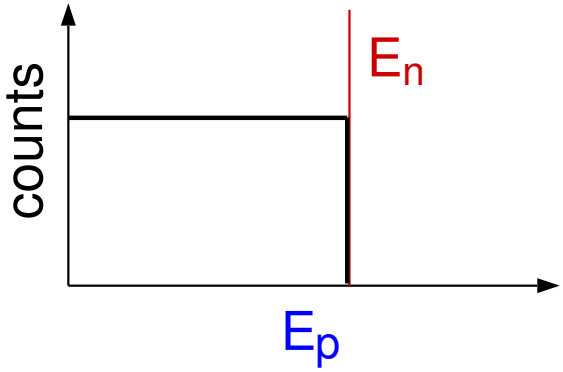


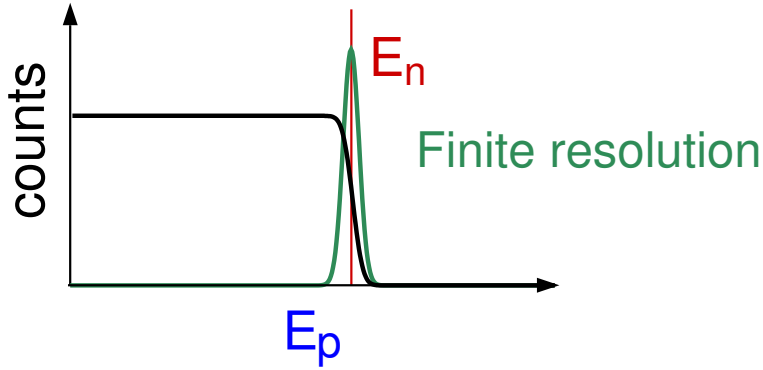




$E_p(\vartheta) = E_n \cos^2(\vartheta/2) \leq E_n$

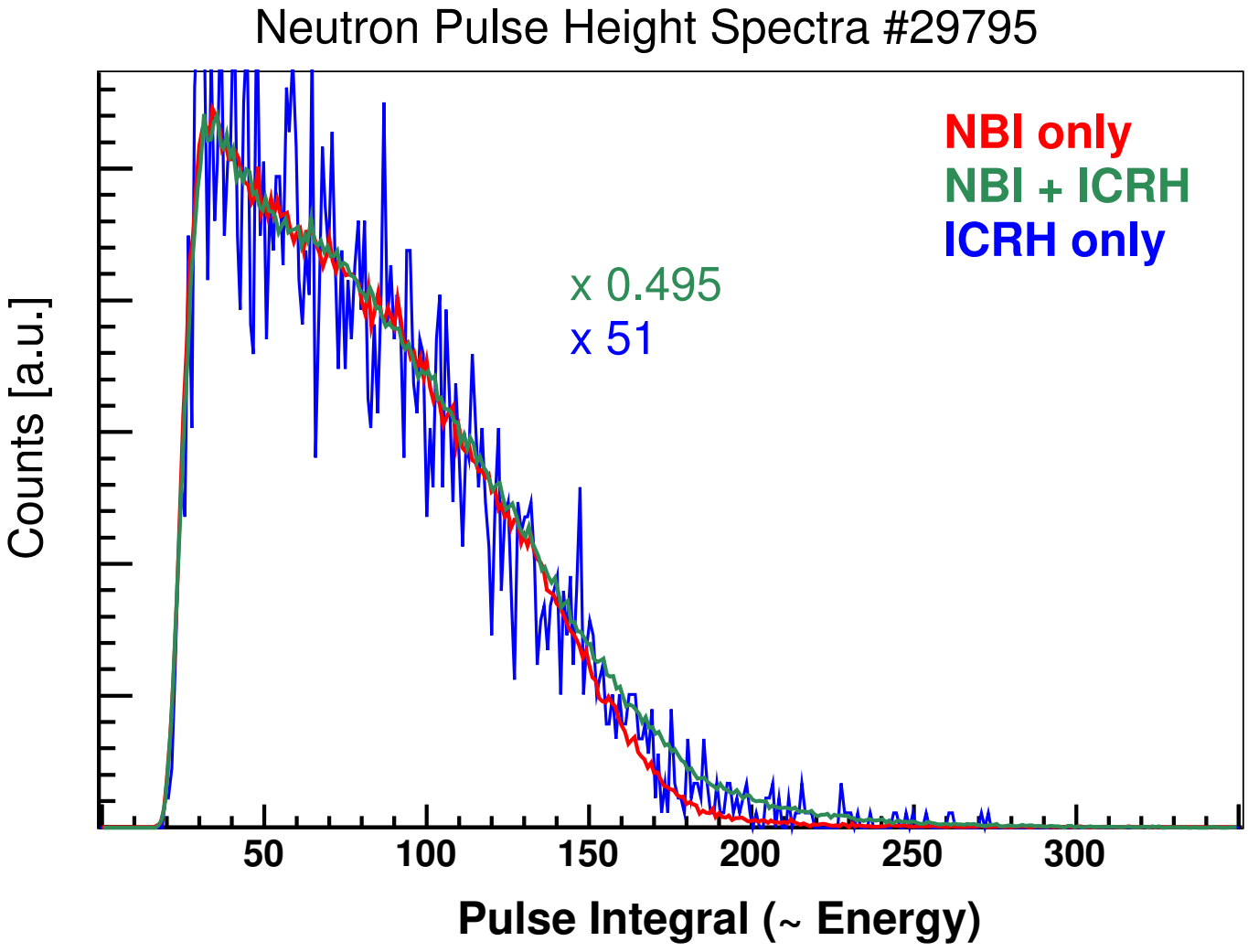
ϑ dependence cancels: #neutrons increases with scattering parameter



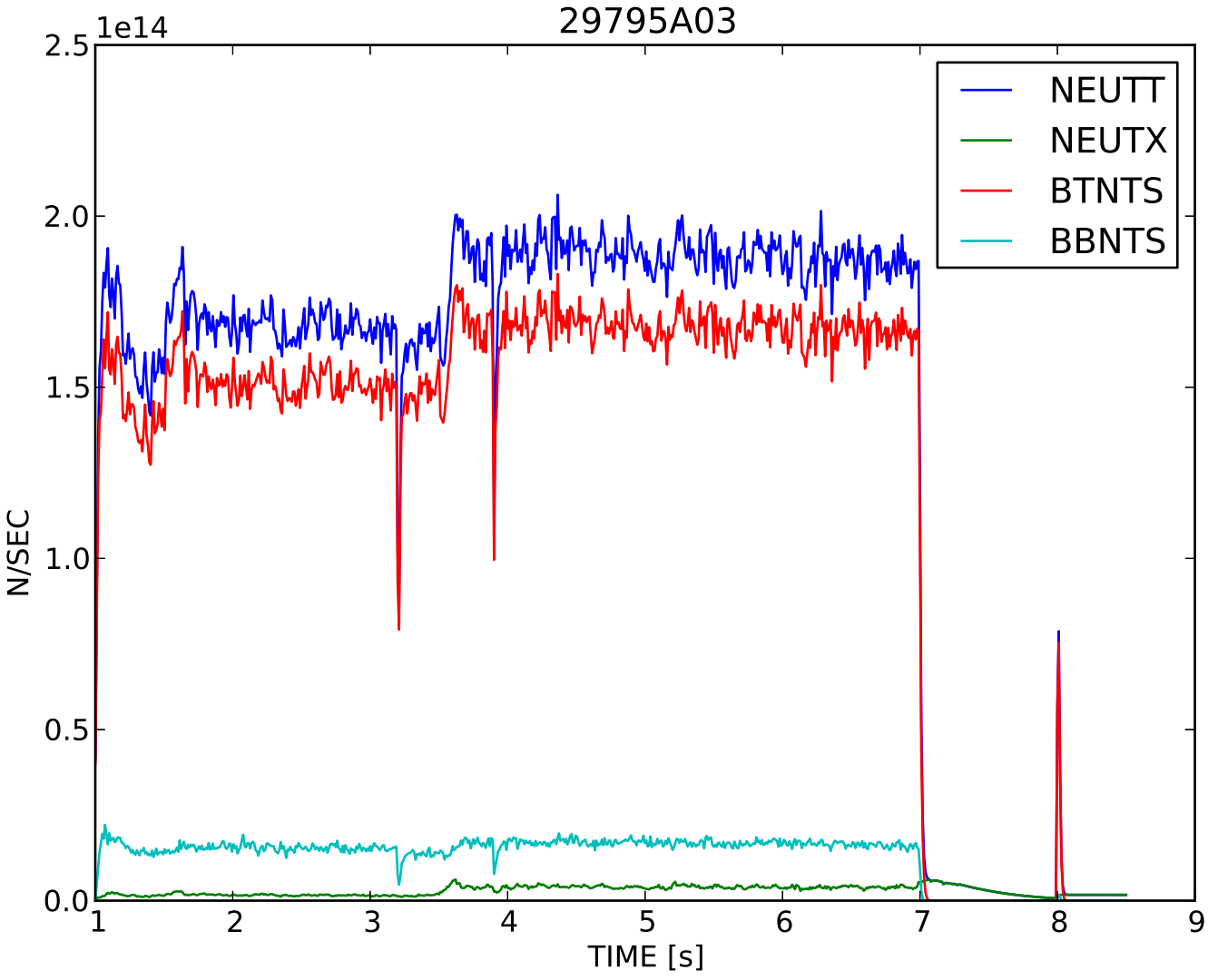


- Detector + DAQ details in [Tardini JINST 13]
- Neutron energy spectrum $\Longrightarrow$ superpostion (broader edges)
- Detector response varies with energy (PMT efficiency, other scattering)

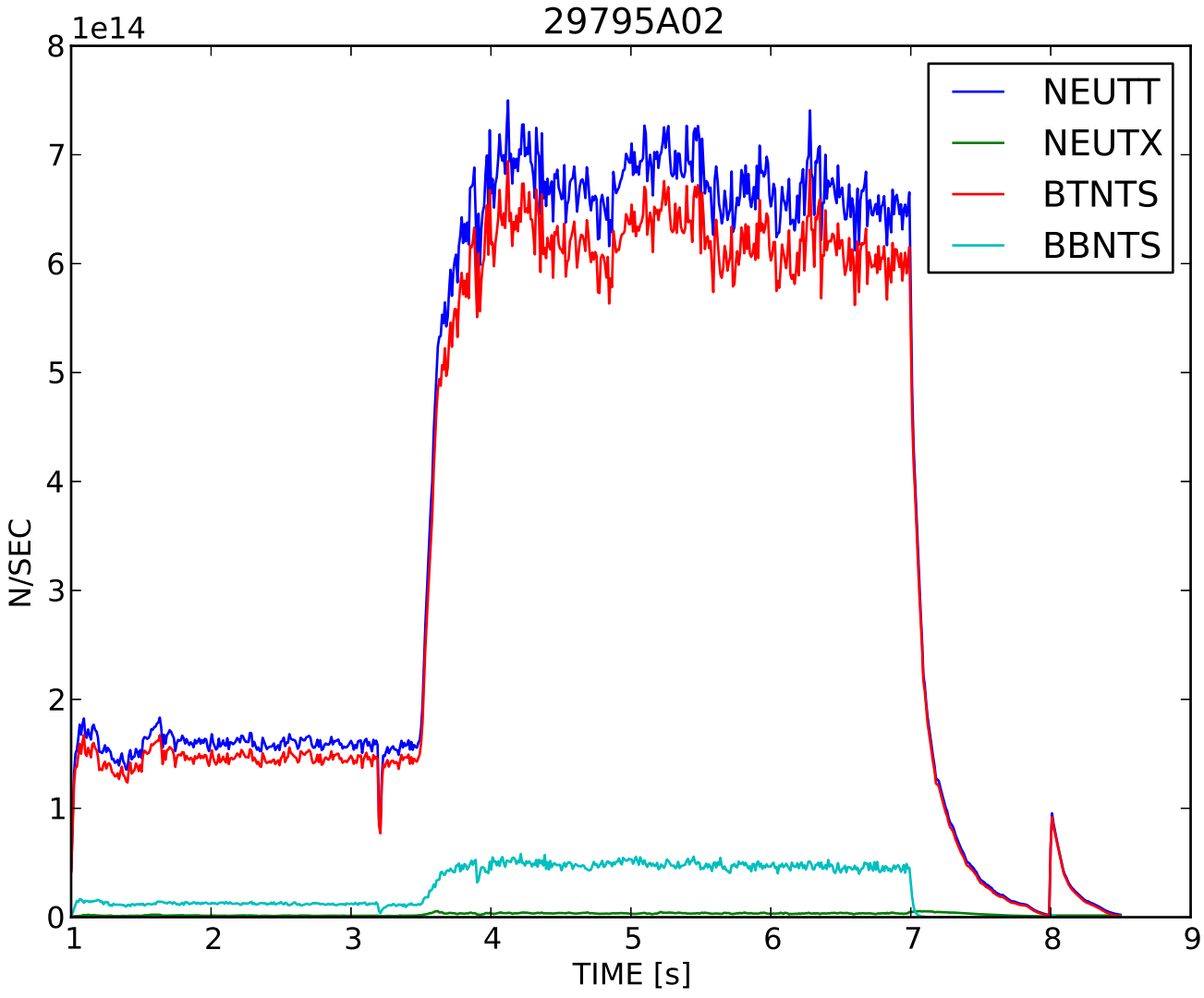
ICRF only phase



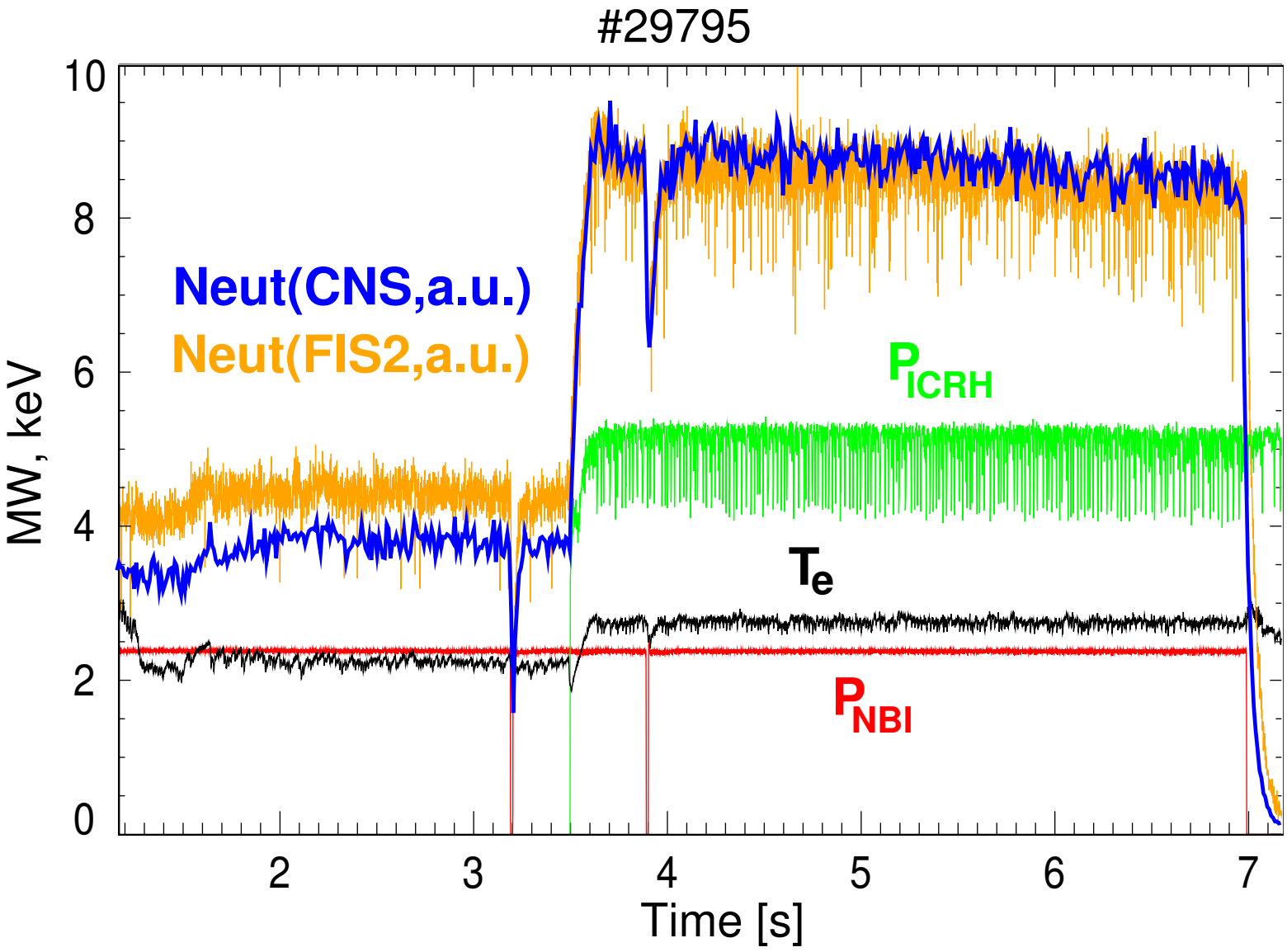
TRANSP, no RF-kick operator



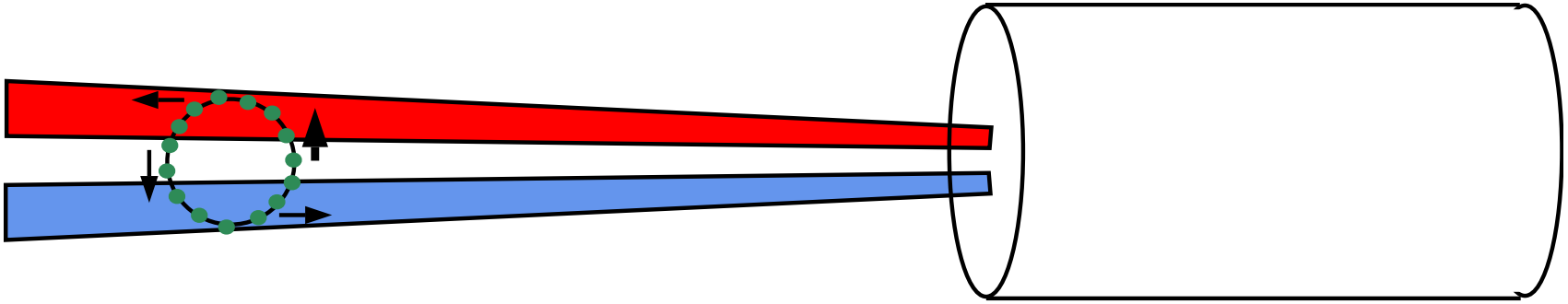
TRANSP, with RF-kick operator



Time traces


#29795
Neut(CNS,a.u.)
Neut(FIS2,a.u.)
P_ICRH
T_e
P_NBI
MW, keV
Time [s]
0
2
4
6
8
10
2
3
4
5
6
7

Double peak in NES



- Many more red- blue-shifted fast ions projected in the LOS
  $\Longrightarrow$ more fusion reactions coming for $v_{D,\perp} \parallel$ LOS