



Fast ion distribution in TRANSP

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1. How to produce Fast Ion (FI) distribution in TRANSP
2. MATLAB routine to read the FI distribution output
3. Examples of the FI distribution output

Modify TRANSP namelist to produce Fast Ion distribution output



- During the step 'config', specify SELAVG, OUTTIM, and AVGTIM in the namelist.
 - A basic set of data for fast ion distribution functions.
i.e. **SELAVG='FBM BMVOL BDENS2 EBA2PL EBA2PP'**
 - Times of interest for fast ion distributions
i.e. **OUTTIM=5.5, 8.0, 10.5** %Timeslices can be selected upto five
 - Averaging time
i.e. **AVGTIM= 0.3** % Note, fast ion distribution output is averaged over the time range **OUTTIM(j)-AVGTIM** to **OUTTIM(j)**.

Convert the data format to cdf file (e.g. 83479D07_fi_5.cdf)



- Once the run is completed, then 'fast ion data files' (e.g. 83479D07.DATA5) are saved in the \$TWD (i.e. /common/transp_shared/Data/work/hkim/JETtest/83479/83479D07).
- Since the fast ion data file is not a directly readable format, it should be converted to cdf format using 'get_fbm', which is a routine in TRANSP.
- Enter 'get_fbm' in the TRANSP window to start the routine.

get_fbm (1)



%get_fbm

19-Jan-2015 12:10:47 = time of run

10-Dec-2008 = time of compil

5 Jan 2009 -- Recent modification by M.Gorelenkova:

ACfiles with both fbm(GC) and fbm(ptcl) can be read.

dmc 10 Dec 2008 -- NetCDF read option added.

dmc 10 May 2007 -- Deposition Distribution Function upgrade.

dmc 18 Sep 2004 -- NetCDF write option added.

*** see source/doc/fbm.doc ***

*** for information on normalization & units ***

%enter "Q" to quit.

%enter "N" to read NetCDF instead of TRANSP data.

[OLD VALUE: ""]

GET_FBM: ENTER TRANSP RUN ID (MAX 8 CHARS):

[fgetline: no command line editing available]

83479D07

%specify file directory: "Q" for current working directory...

Unixpath: current path: " "

translated path: " "

(blank means default, use current working directory)

Enter "d" or "D" to use default,

enter "a" or "A" to append to current path,

enter "q" or "Q" to use current setting,

or enter a path string to specify a new path. If the first character of the path string is neither "/" nor "~" then the first word of the path string may be taken as an environment variable, to be translated on output.

[OLD VALUE: " ..."]

unixpath: enter path string or option code:

get_fbm (2)



/common/transp_shared/Data/work/hkim/JETtest/83479/83479D07

Unixpath: current path: "/common/transp_shared/Data/work/hkim/JETtest/83479/83479D07"

translated path: "/common/transp_shared/Data/work/hkim/JETtest/83479/83479D07"

(blank means default, use current working directory)

Enter "d" or "D" to use default,

enter "a" or "A" to append to current path,

enter "q" or "Q" to use current setting,

or enter a path string to specify a new path. If the first character of the path string is neither "/" nor "~" then the first word of the path string may be taken as an environment variable, to be translated on output.

[OLD VALUE: "/common/transp_shared/Data/work/hkim/JETtest/83479..."]

unixpath: enter path string or option code:

q

GET_FBM: ENTER FILE ID (# BTW 0 AND 9):

5

get_fbm (3)



```
TRANSP "AC" FILE 83479D07.DATA5 SUCCESSFULLY OPENED.
WRITTEN BY TRANSP AT TIME T = 1.30000E+01 FORMAT CODE = 1
Time average over preceeding 1.00000E+00 seconds.
%ACDATRD: FBM: real -> real*8 conversion.
%ACDATRD: FBM_PTCL: real -> real*8 conversion.
INPUT DATA VERSION # 3
%get_fbm: reading: NSTAT_TRACK_XJA
pinja = 1635027.926098114 1677466.771935126 1929673.651539885 1778282.321297805 1966080.125000000 1931499.230450246 1602724.116734496
1699191.372669513 2072534.375000000 0.000000000000000E+00 1709949.250000000 1757891.750000000 1629690.074638915 1677284.524013728
%get_fbm: reading: TRACK_DE_FLR
%get_fbm: reading: TRACK_DR_FLR
%get_fbm: reading: TRACK_DVPV_FLR
%get_fbm: reading: TRACK_DZ_FLR
%get_fbm: reading: TRACK_PDEP
%get_fbm: reading: TRACK_VPV_DEP
%get_fbm: reading: TRACK_XL

*** equilibrium is NOT updown symmetric ***

%get_fbm: fbm available out to r/a = 1 only.
5 fast ion species
Species#  A  Z  classification      deposition data? (T/F)
  1    2.0  1.0  NEUTRAL BEAM      (NBI)   T
  2    3.0  1.0  FUSION PRODUCT    (FUSN)  T
  3    3.0  2.0  FUSION PRODUCT    (FUSN)  T
  4    4.0  2.0  FUSION PRODUCT    (FUSN)  T
  5    1.0  1.0  RF MINORITY       (RFI)   F
```

get_fbm (4)



%get_fbm: lost particle data available
for OUTPUT Ufiles:
tokamak label: "?????"
path (blank for cwd):
%enter "T" to reset tokamak label
%enter "X" to reset output file path
%enter "F" to reset NetCDF file name: current value: 83479D07_fi_5.cdf
%enter "W" to write NetCDF file (R8 precision)
%enter "V" to write NetCDF file (R8; omit deposition and lost ptcl data)
(R4 output option removed).
%enter "N" to write NetCDF 2d file for neutron emission
%enter "Q" to read another dataset.
Choose species# or Option code:
I
[OLD VALUE: "?????"]
new 3 or 4 character tokamak label:
JET

get_fbm (5)



5 fast ion species

Species#	A	Z	classification	deposition data? (T/F)
1	2.0	1.0	NEUTRAL BEAM	(NBI) T
2	3.0	1.0	FUSION PRODUCT	(FUSN) T
3	3.0	2.0	FUSION PRODUCT	(FUSN) T
4	4.0	2.0	FUSION PRODUCT	(FUSN) T
5	1.0	1.0	RF MINORITY	(RFI) F

%get_fbm: lost particle data available

for OUTPUT Ufiles:

tokamak label: "JET "

path (blank for cwd):

%enter "T" to reset tokamak label

%enter "X" to reset output file path

%enter "F" to reset NetCDF file name: current value: 83479D07_fi_5.cdf

%enter "W" to write NetCDF file (R8 precision)

%enter "V" to write NetCDF file (R8; omit deposition and lost ptcl data)
(R4 output option removed).

%enter "N" to write NetCDF 2d file for neutron emission

%enter "Q" to read another dataset.

Choose species# or Option code:

W

get_fbm (6)



options:

- C -- distribution function at guiding center.
- P -- distribution function at particle location.

get_fbm: enter option code:

C

distribution function at guiding center will be saved

specie: D_NBI

Total #of fast ions (fbm): 5.7977E+19

Total #of fast ions (bdens2): 5.7977E+19

(these numbers should match roughly).

specie: T_FUSN

Total #of fast ions (fbm): 1.8877E+15

Total #of fast ions (bdens2): 1.8876E+15

(these numbers should match roughly).

specie: He3_FUSN

Total #of fast ions (fbm): 4.8592E+14

Total #of fast ions (bdens2): 4.8596E+14

(these numbers should match roughly).

specie: He4_FUSN

Total #of fast ions (fbm): 1.5859E+13

Total #of fast ions (bdens2): 1.5858E+13

(these numbers should match roughly).

specie: H_RFI

Total #of fast ions (fbm): 0.0000E+00

Total #of fast ions (bdens2): 0.0000E+00

(these numbers should match roughly).

==> wrote 83479D07_fi_5.cdf

get_fbm (7)



5 fast ion species

Species#	A	Z	classification	deposition data? (T/F)
1	2.0	1.0	NEUTRAL BEAM (NBI)	T
2	3.0	1.0	FUSION PRODUCT (FUSN)	T
3	3.0	2.0	FUSION PRODUCT (FUSN)	T
4	4.0	2.0	FUSION PRODUCT (FUSN)	T
5	1.0	1.0	RF MINORITY (RFI)	F

%get_fbm: lost particle data available

for OUTPUT Ufiles:

tokamak label: "JET "

path (blank for cwd):

%enter "T" to reset tokamak label

%enter "X" to reset output file path

%enter "F" to reset NetCDF file name: current value: 83479D07_fi_5.cdf

%enter "W" to write NetCDF file (R8 precision)

%enter "V" to write NetCDF file (R8; omit deposition and lost ptcl data)
(R4 output option removed).

%enter "N" to write NetCDF 2d file for neutron emission

%enter "Q" to read another dataset.

Choose species# or Option code:

Q

%enter "Q" to quit.

%enter "N" to read NetCDF instead of TRANSP data.

[OLD VALUE: "83479D07 "]

GET_FBM: ENTER TRANSP RUN ID (MAX 8 CHARS):

Q

❖ ***83479D07_fi_5.cdf is produced in \$TWD after these steps.***

Matlab routine to read cdf file (provided by Simppa Äkäslompolo)



```
filename = '\\samba-pub-9\TRANSPshared\Data\work\hkim\JETtest\83479\83479D07\83479D07_fi_2.cdf'
```

```
tra.filename=filename;
```

Note, ncread is a built-in function to read netcdf files in matlab, but it is not available in old Matlab version like one installed in JAC

```
tra.grid.z =ncread(filename,'Z2D')/100; %m
```

```
tra.grid.r =ncread(filename,'R2D')/100; %m
```

```
tra.grid.theta=ncread(filename,'TH2D');
```

```
tra.grid.X =ncread(filename,'X2D');
```

Volume of differential 'toroidal tube'

```
tra.grid.volumes =ncread(filename,'BMVOL');%cm3
```

```
tra.pitch =ncread(filename,'A_D_NBI');
```

```
tra.pitch_boundary=ncread(filename,'AB_D_NBI');
```

```
tra.energy =ncread(filename,'E_D_NBI'); %eV
```

```
tra.energy_boundary=ncread(filename,'EB_D_NBI');
```

```
tra.energy_units='eV';
```

```
tra.dist =ncread(filename,'F_D_NBI') * 0.5 ;
```

$$\begin{aligned} f^s(E, g, R, Z) & \text{ in } [\#/cm^3/eV/dg] \\ dg &= \frac{d\Omega}{4\pi} = \frac{1}{4\pi} \sin\theta d\theta d\phi = \frac{1}{2} \sin\theta d\theta \text{ (i.e. toroidal symmetry)} \\ &= \frac{1}{2} d(-\cos\theta) = \frac{1}{2} dp \\ \int f^s dg &= \int \frac{1}{2} f^s dp \\ \frac{1}{2} f^s &= f(E, p, R, Z) \text{ in } [\#/cm^3/eV/dp] \end{aligned}$$

```
tra.dist_units=ncreadatt(filename,'F_D_NBI','units');
```

```
tra.time=ncread(filename,'TIME');
```

```
tra.runid=ncread(filename,'TRANSP_RUNID');
```

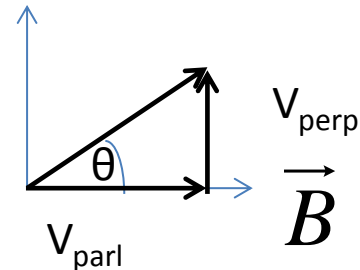
Fast ion distribution function i.e. $f(E,p,R,Z)$



❖ tra.dist = $f(E, p, R, Z)$ in [$\#/cm^3/eV/dp$]

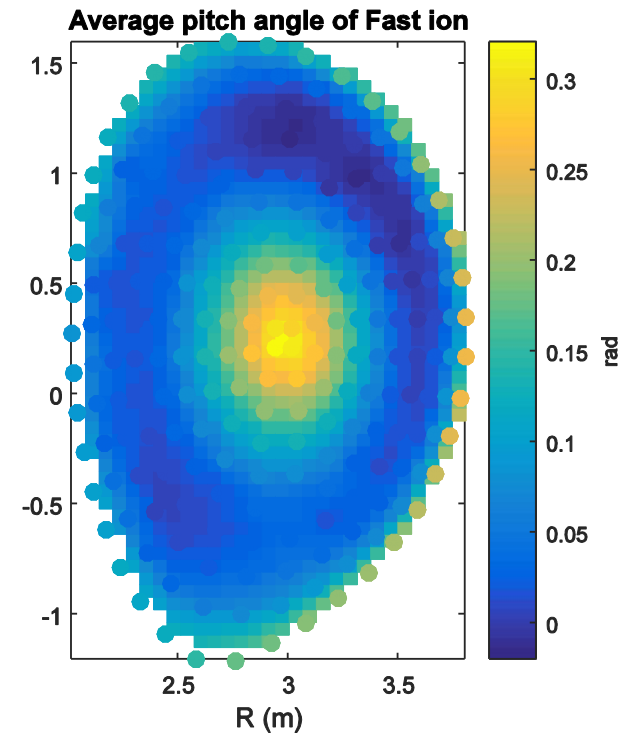
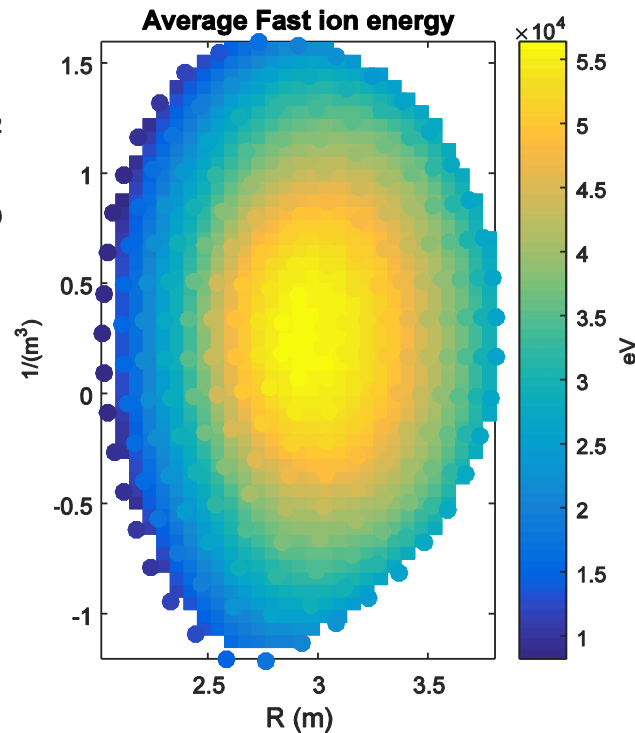
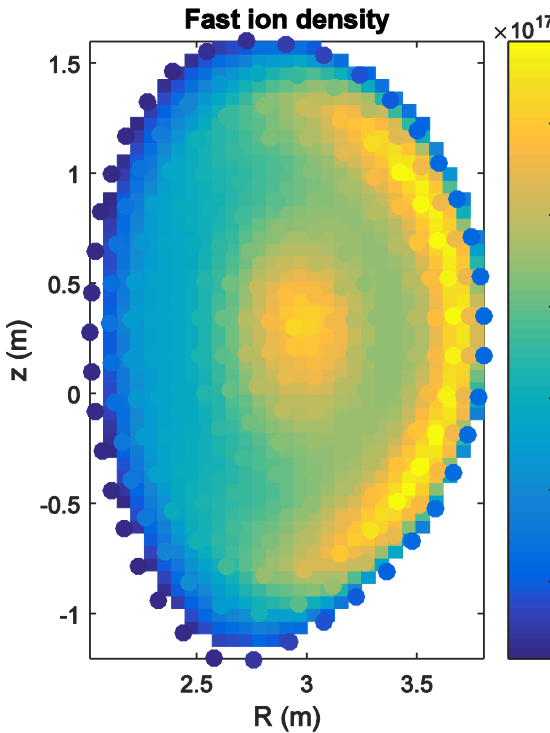
• $E = 0.5 m_{FI} (V_{\text{perp}}^2 + V_{\text{parl}}^2)$ in [eV]

• $p = \cos(\theta)$ where $0 < \theta < \pi$



• R and Z are major radius and Z position in [m]

2D distribution of FI(Fast Ion) density, FI average energy, and FI average pitchangle



$$\int_0^{\infty} \int_{-1}^1 f(E, p, R, Z) dE dp$$

$$= n_{FI}(R, Z)$$

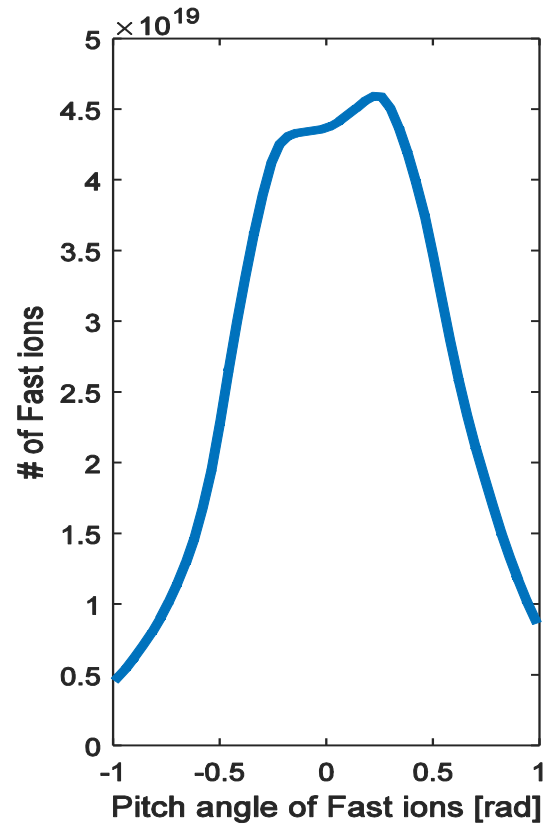
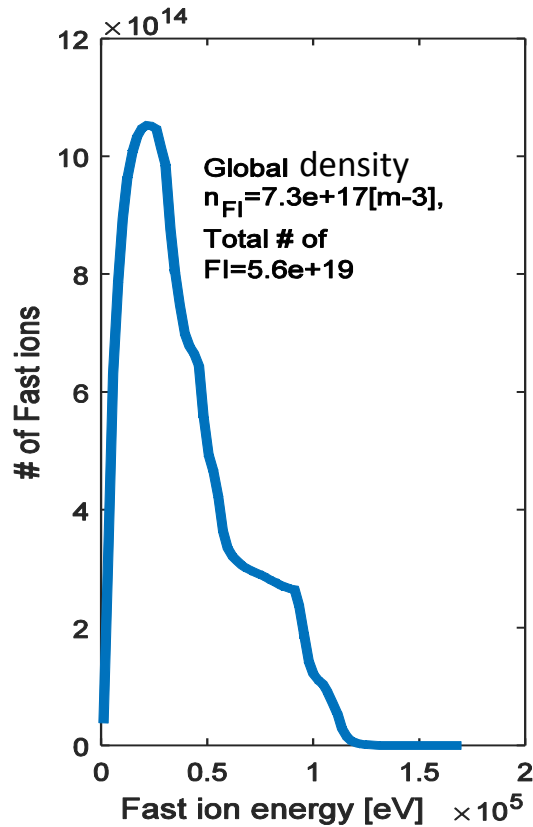
$$\frac{\int_0^{\infty} \int_{-1}^1 E f(E, p, R, Z) dE dp}{\int_0^{\infty} \int_{-1}^1 f(E, p, R, Z) dE dp}$$

$$= \langle E(R, Z) \rangle$$

$$\frac{\int_0^{\infty} \int_{-1}^1 p f(E, p, R, Z) dE dp}{\int_0^{\infty} \int_{-1}^1 f(E, p, R, Z) dE dp}$$

$$= \langle p(R, Z) \rangle$$

of Global fast ions



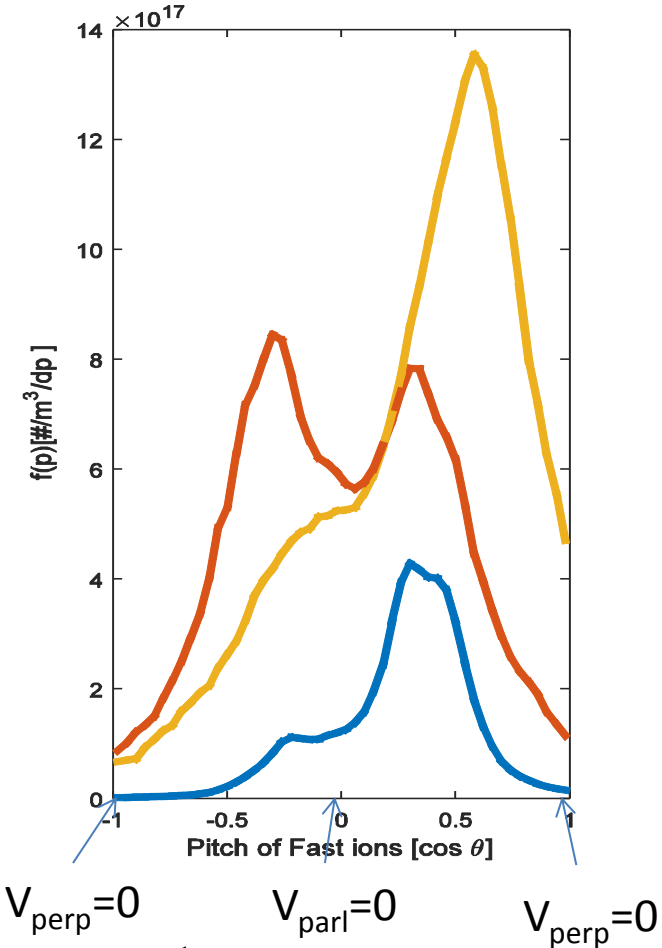
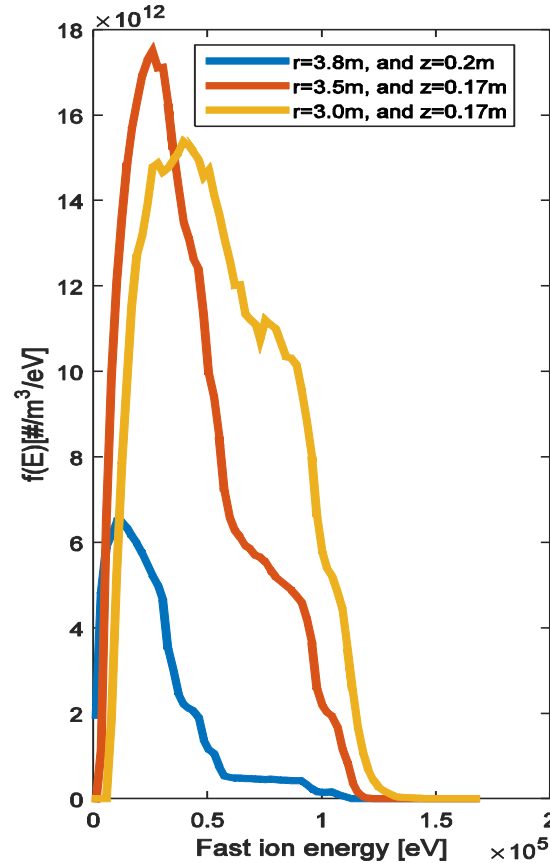
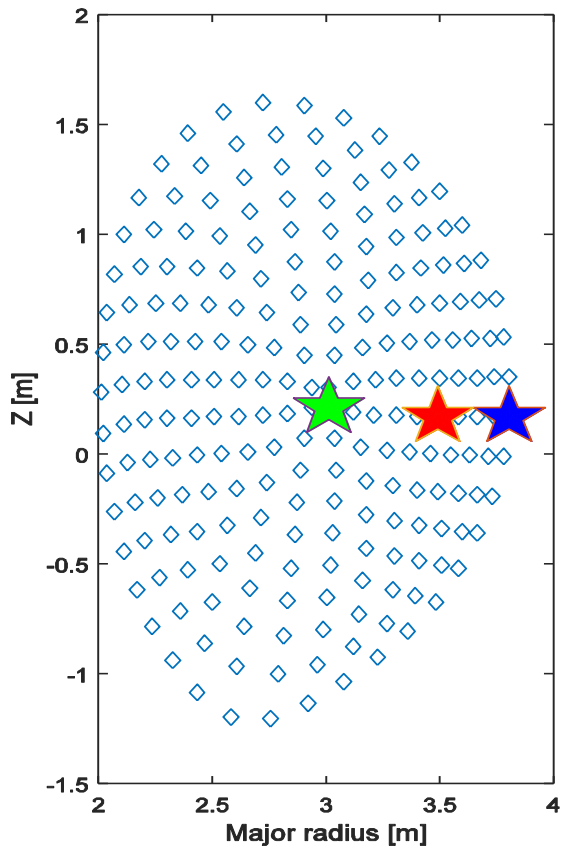
$$\int_0^{\infty} \int_{-1}^1 f(E, p, R, Z) dV dp$$

= global $N_{FI}(E)$

$$\int_0^{\infty} \int_{-1}^1 f(E, p, R, Z) dV dE$$

= global $N_{FI}(p)$

Energy and pitch angle distribution at a specific position in (R,Z)



$$\int_{-1}^1 f(E, p, R, Z) dp$$

$$= N_{FI}(E, R, Z)$$

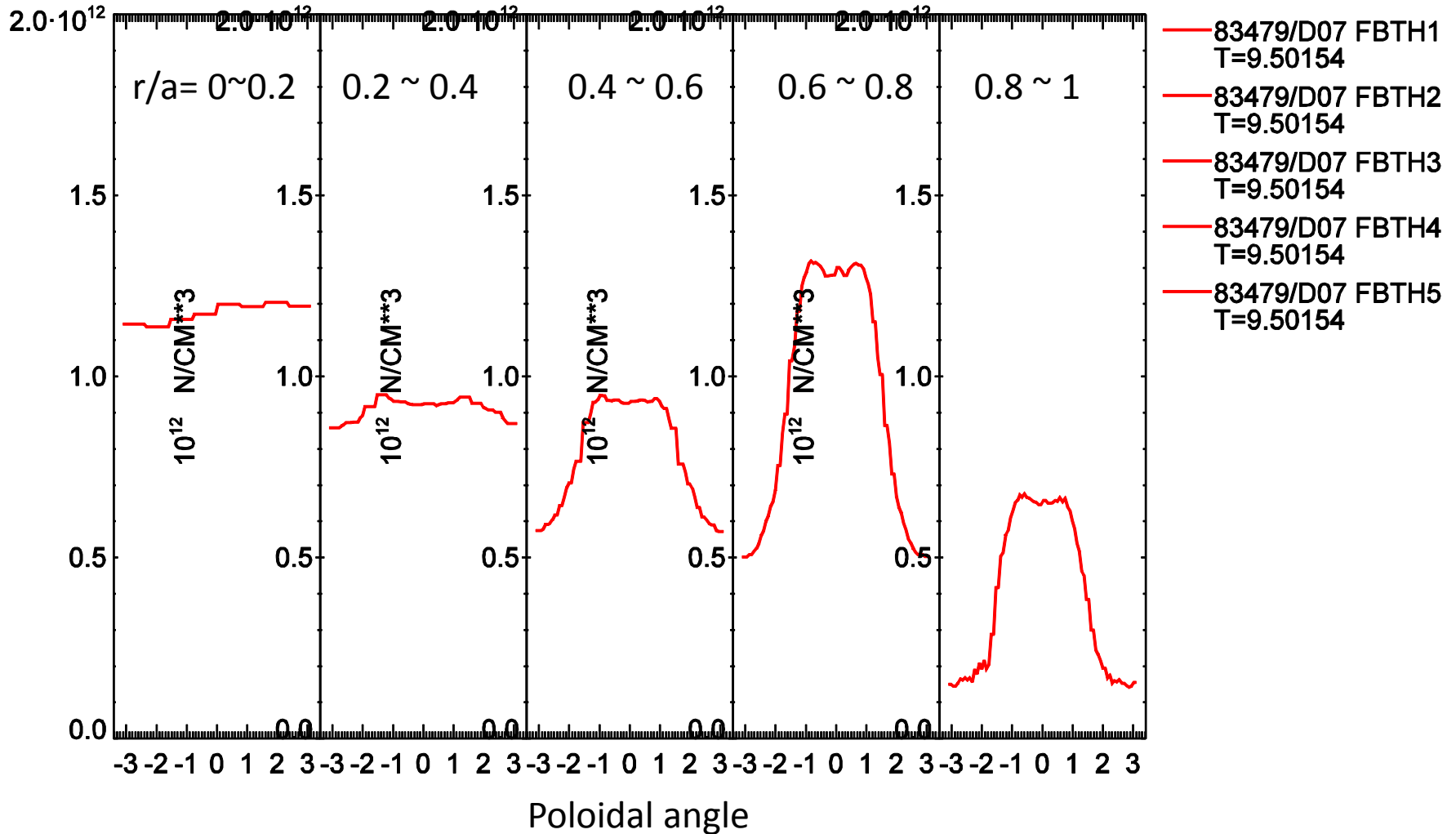
$$\int_{-1}^1 f(E, p, R, Z) dE$$

$$= N_{FI}(p, R, Z)$$

FBTH in JETDSP (Fast ion density)



JET Data Display



FI CDF file (tra.dist) vs JETDSP (FBTH#)



```
%tra.dist = f(E, p, R,Z) in [#/cm3/eV/dp]
```

```
tra.n_fi=squeeze(sum(sum(tra.dist,2),1));
```

```
tra.n_fi=tra.n_fi; % cm-3
```

```
tra.n_fi=tra.n_fi*(tra.pitch_boundary(2)-tra.pitch_boundary(1));
```

```
tra.n_fi=tra.n_fi*(tra.energy_boundary(2)-tra.energy_boundary(1));
```

```
%tra.n_fi = fast ion density in each grid (220 x 1)
```

```
%tra.grid.theta = poloidal angle in each grid (220 x 1)
```

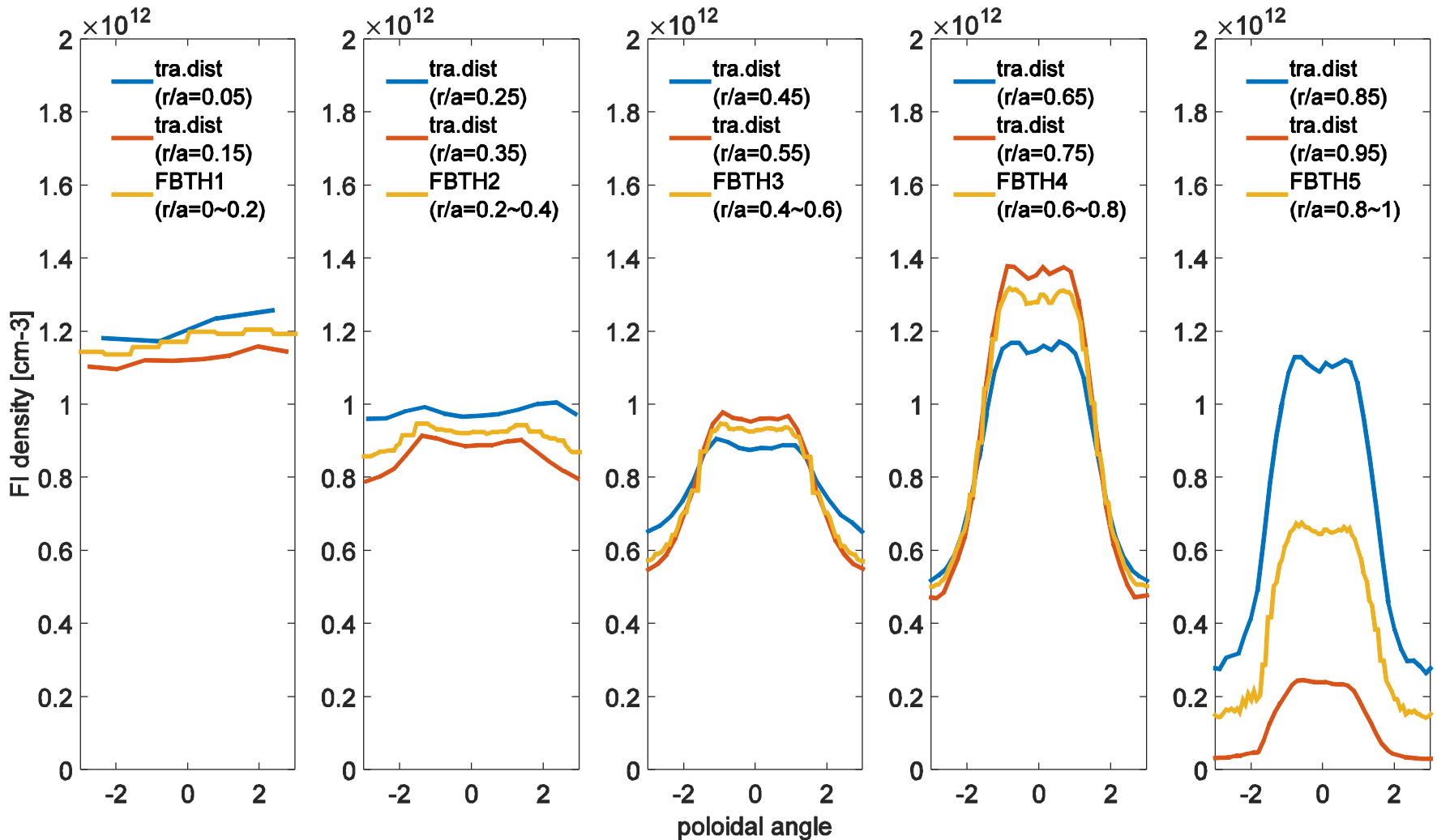
```
%tra.grid.X = r/a in each grid (220 x 1)
```

```
%Note, tra.grid.X(1:4)=0.05 i.e. r/a=0.05, and tra.grid.X(5:12)=0.15 i.e. r/a=0.15
```

```
plot(tra.grid.theta(1:4),tra.n_fi(1:4),tra.grid.theta(5:12),tra.n_fi(5:12),  
TRANSP_poloidal_angle,FBTH1)
```

$$\int_0^{\infty} \int_{-1}^1 f(E, p, \theta, \frac{r}{a}) dE dp$$
$$= n_{FI}(\theta, \frac{r}{a})$$

FI CDF file (tra.dist) vs JETDSP (FBTH#)

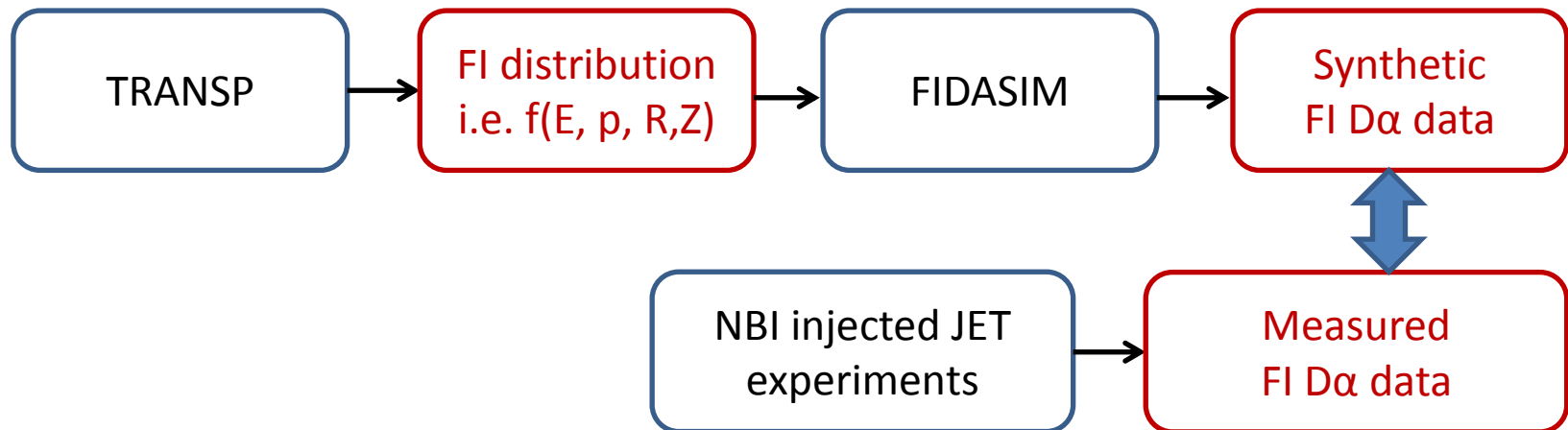


FI distribution in the CDF files, which is obtained by get_fbm, are consistent with the general TRANSP output saved in JETDSP.

Future work – validation of TRANSP FI distribution at JET



- FIDASIM, a code that models the signal produced by charge-exchange reactions between fast-ions and injected neutral beams, is installed at JET. Validating TRANSP FI distribution by comparing FIDASIM synthetic data (using FI distribution from TRANSP) with JET experiment.



Conclusion



- TRANSP can produce fast ion distribution as a function of fast ion energy, pitch, and spatial position R and Z (or θ and ρ)
i.e. $f(E, p, R, Z)$ in [$\#/cm^3/eV/dp$]
- FI distribution in the CDF files, which is obtained by `get_fbm`, are consistent with the general TRANSP output saved in JETDSP.
- TRANSP FI distribution will be a very useful tool to investigate fast ion physics, especially for DT experiments.
- Future work – Validation of TRANSP FI distribution using FIDASIM
- Any idea on other applications will be very welcome.