Pitch Angle Resolved Measurements of Neutral Beam Ion Loss from NSTX Plasmas

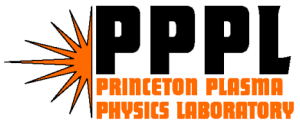
D. Darrow

American Physical Society, Division of Plasma Physics Annual Meeting

November 15–19, 2004

Savannah, GA

This work supported by US DoE contract DE-AC02-76CH03073



Abstract

A scintillator based fast ion loss diagnostic has been installed in NSTX to measure the energy and pitch angle distributions of neutral beam ion loss from NSTX plasmas. Loss is observed at the primary beam energy (80 keV ordinarily, but sometimes as low as 60 keV or as high as 100 keV in this year's experimental campaign). Therefore the observed losses are prompt, occurring before the beam ions slow down significantly. The amplitude of the loss is larger at low plasma currents (<500 kA), as predicted. Various loss signatures have been seen, depending upon details of the discharge condition, including a continuous band of losses over a broad range in pitch angle, and loss localized to one or several discrete pitch angles. MHD activity is frequently correlated with enhanced loss at high pitch angle.

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Motivation

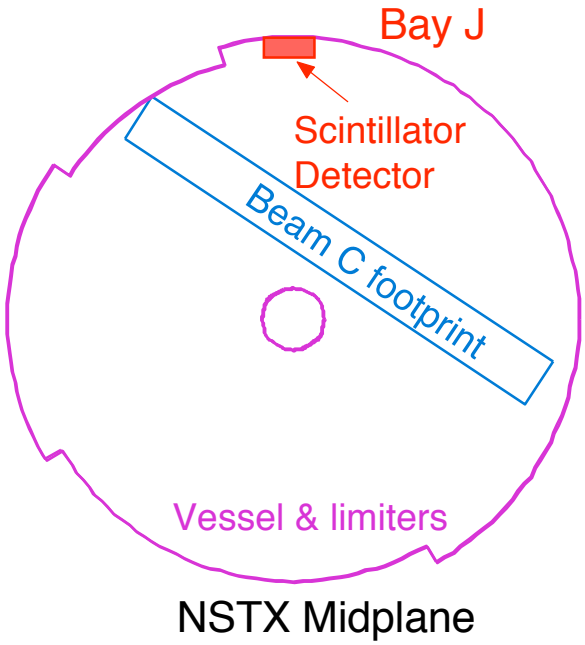
- Lost beam ion characteristics can reveal internal physics, esp. effects of MHD instabilities
- Beam ions have similar dimensionless parameters to 3.5 MeV DT fusion αs in the proposed Next Step Spherical Torus

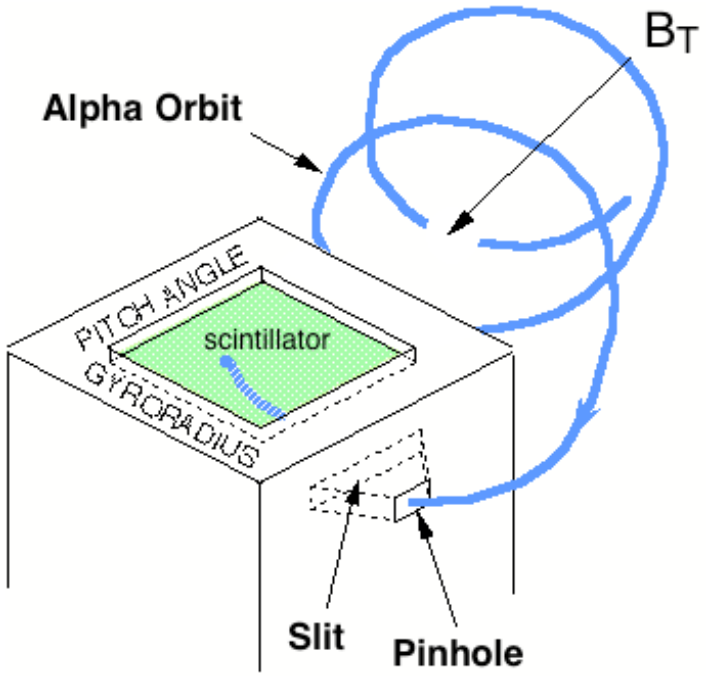
  $\Rightarrow$good model for DT α behavior

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Scintillator beam ion loss probe is magnetic spectrometer

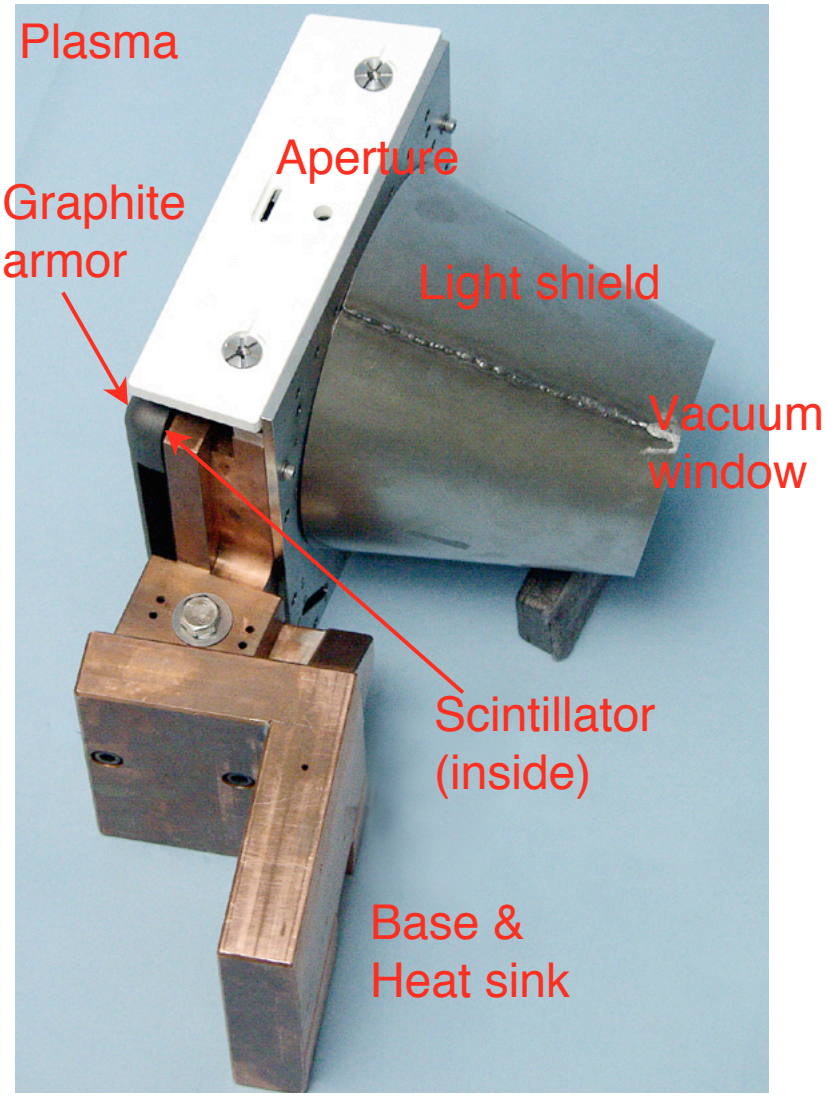
- Combination of B and aperture geometry disperse different pitch angles and energies on scintillator plate

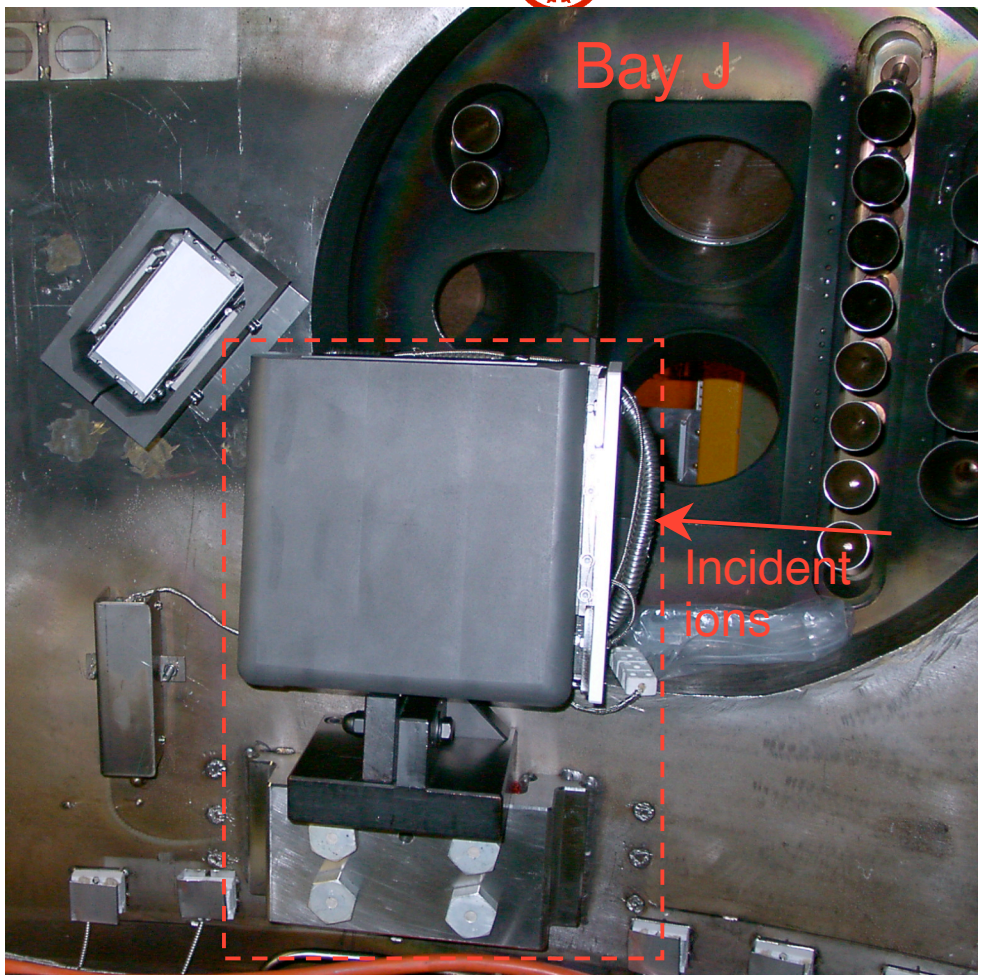




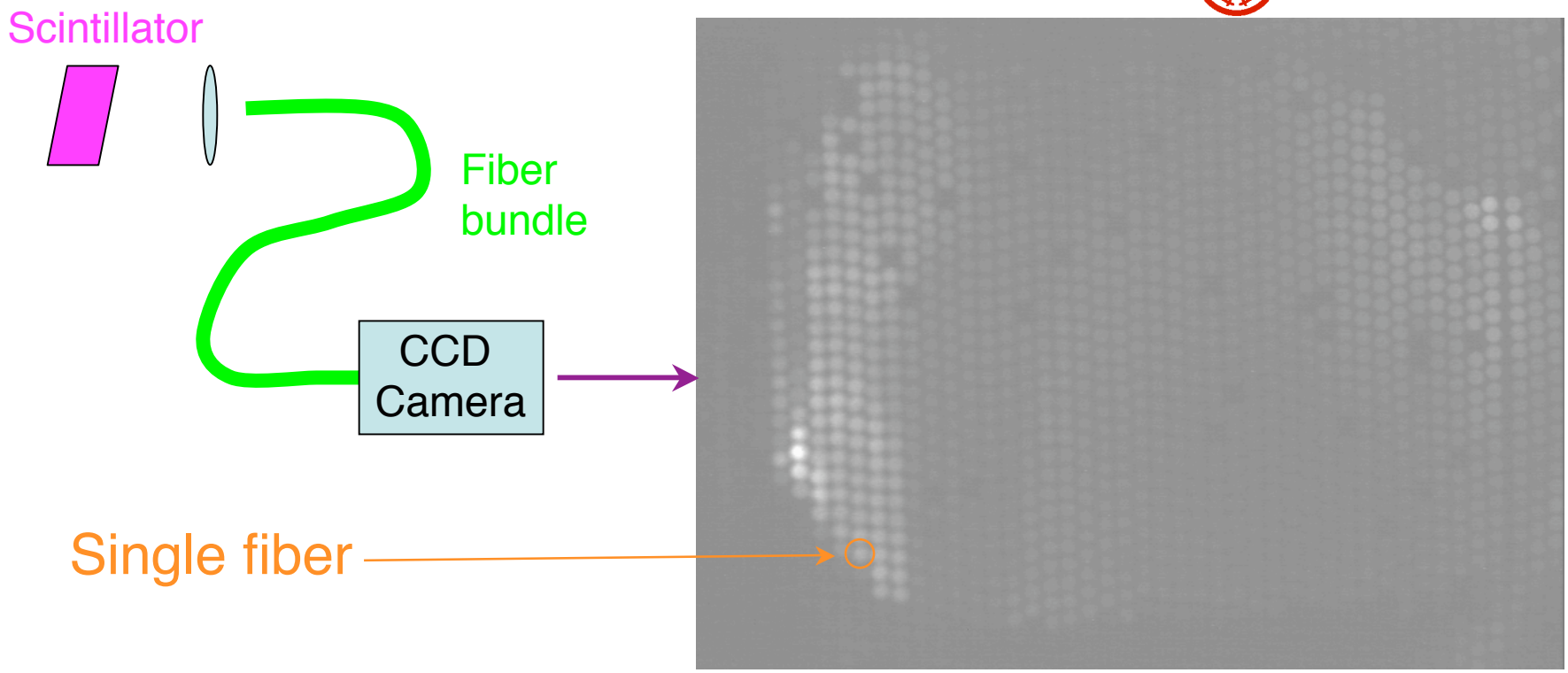
Scintillator detector: principle of operation

Scintillator probe assembly



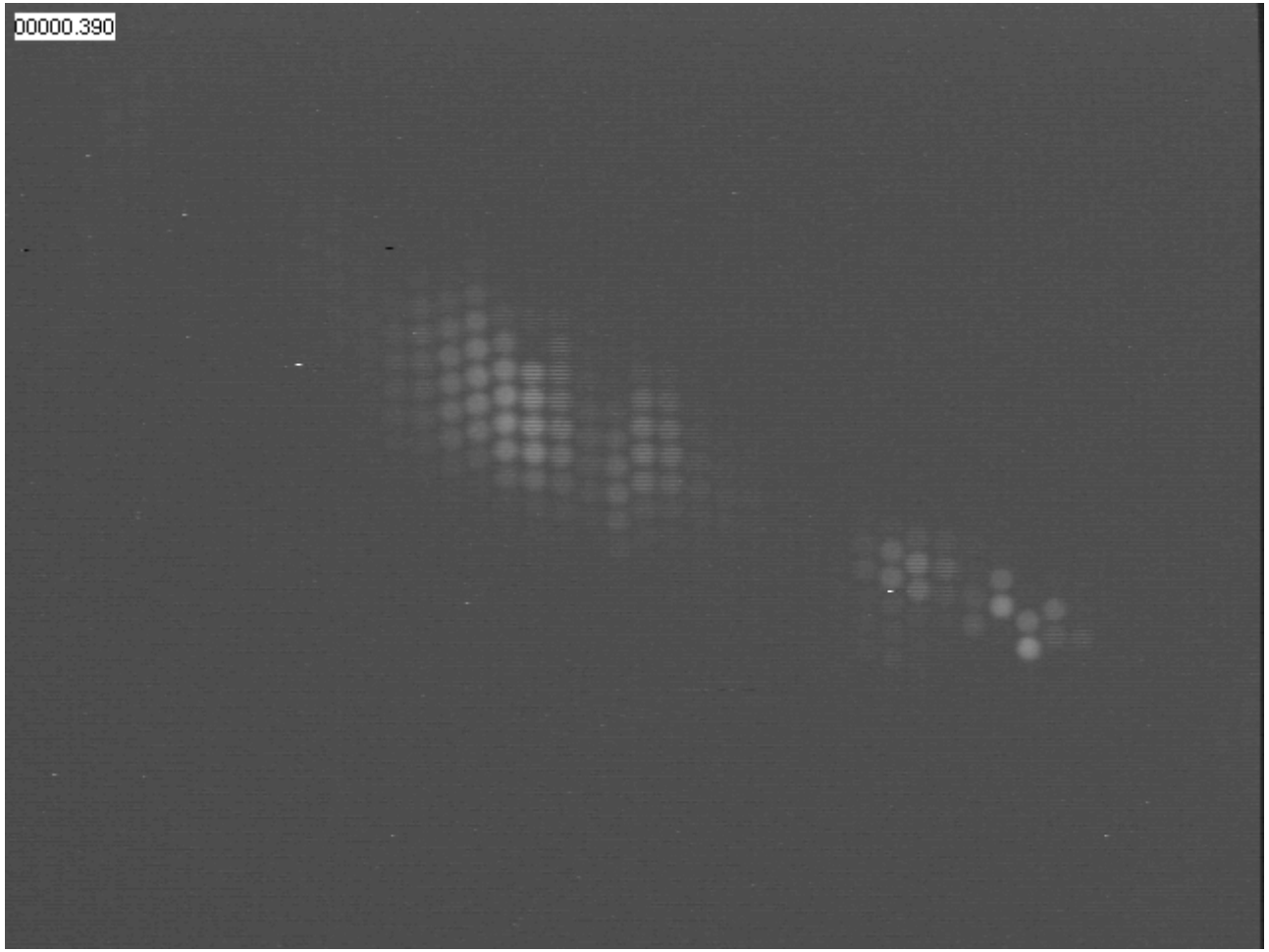


Scintillator image carried by fiber optic bundle to CCD camera



- Limited resolution of bundle (50 x 50) causes discretization of image

Beam ion loss clearly seen



Higher ρ

Lower χ

Higher χ

χ= pitch angle

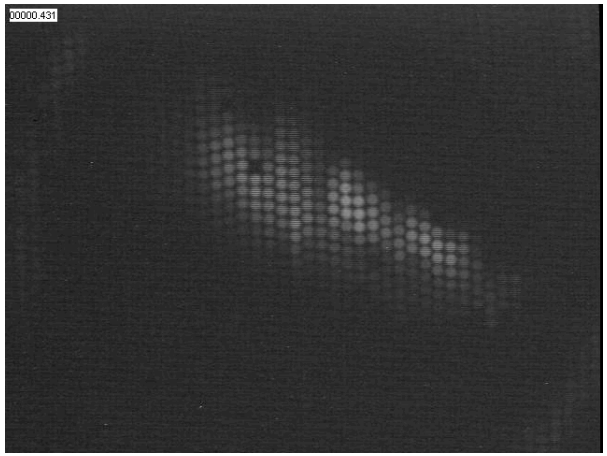
$= \tan^{-1}(v_{||}/v)$

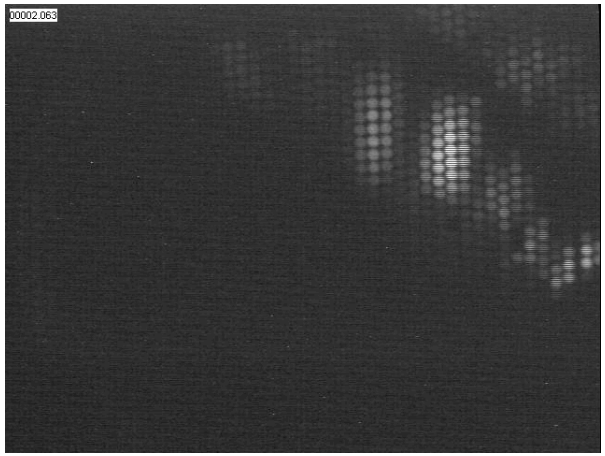
30 frames/s

Lower ρ

112132: 800 kA, 4 MW

Several general classes of loss seen





"Bar" loss: wide χ range

Typically early in NBI:

low n_e & deeper dep'n

(113002, 330 ms)

Multiple discrete χs

(111130)

High χ loss

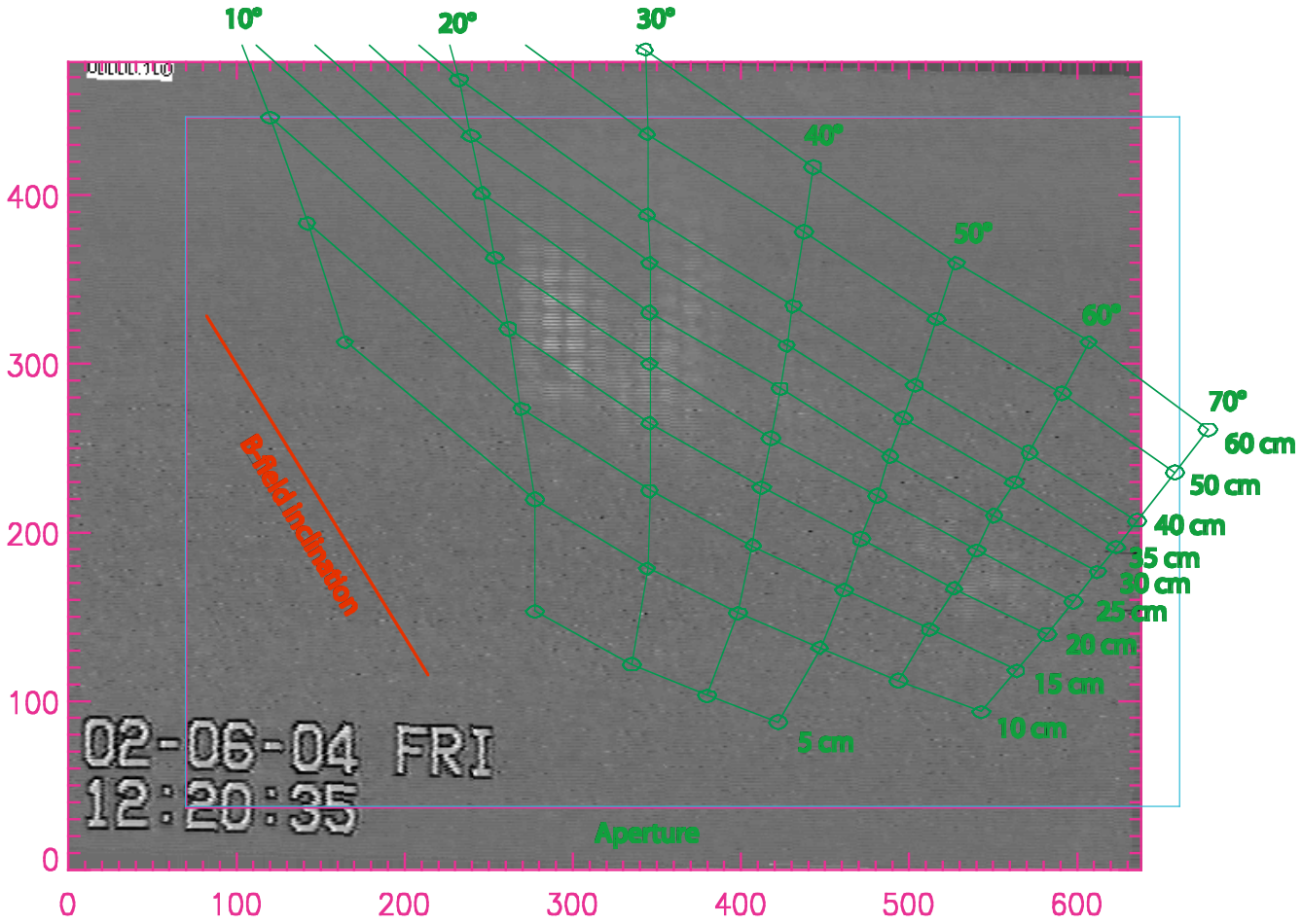
Typ. later in NBI: high n_e

Often modulated by MHD

(112232, 400 ms)

- Very few cases analyzed so far, but all show loss at injection energy (prompt loss)

ρ & χ map can be applied to data



NSTX sFLIP diagnostic, shot 111192, frame 5, with grid for t=169 ms
B=0.2692 T, rho=22 cm, E_D=84 keV, 32 pixels/cm

NSTX

$\chi=\tan^{-1}(v_{||}/v)$

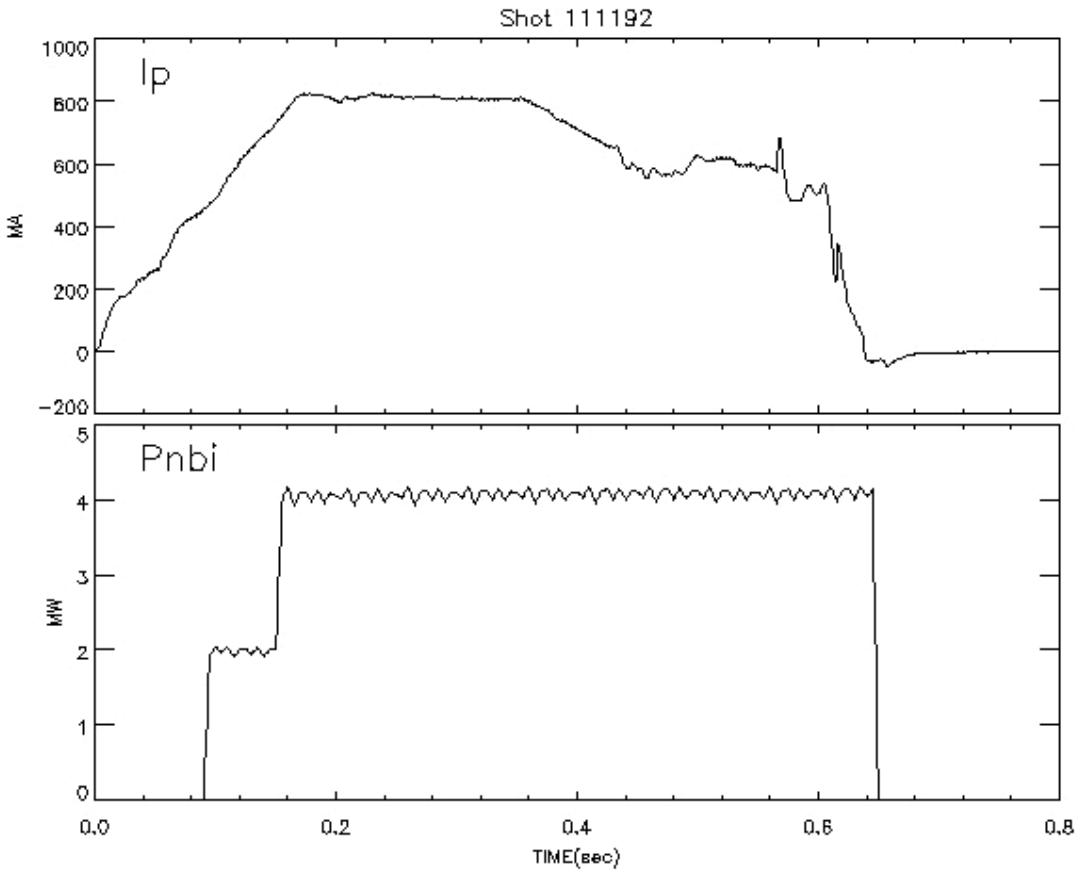
"ρ"$=v/\Omega_i$ (related to energy and independent of χ

Map depends on local B direction relative to apertures

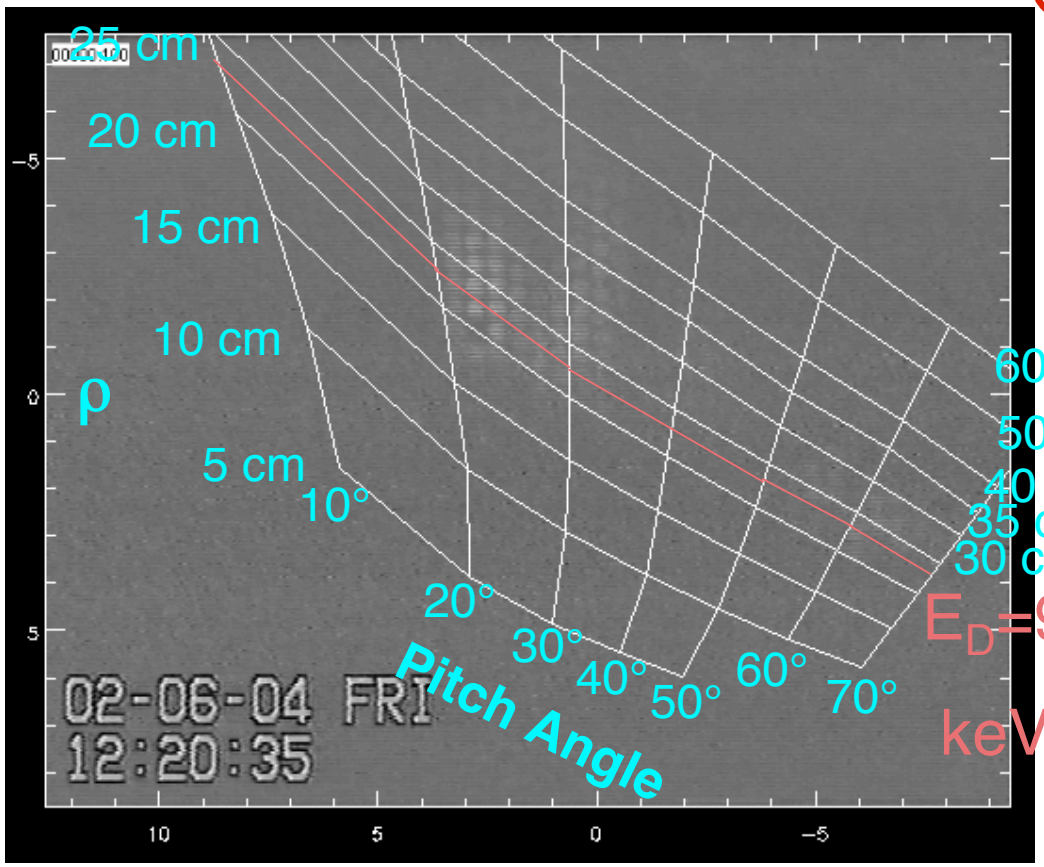
Generated by Monte Carlo model

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Sample shot: 111192

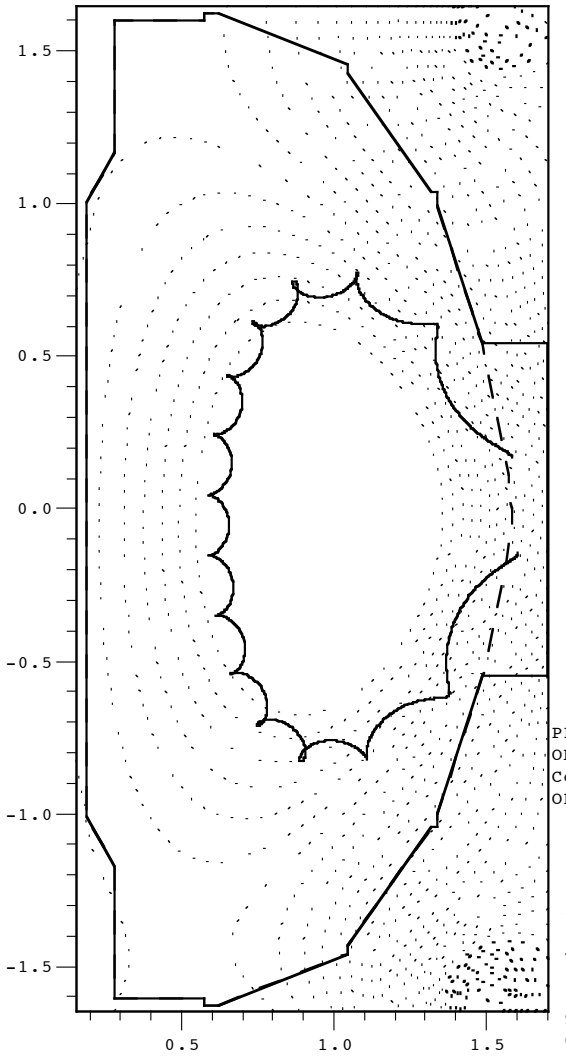


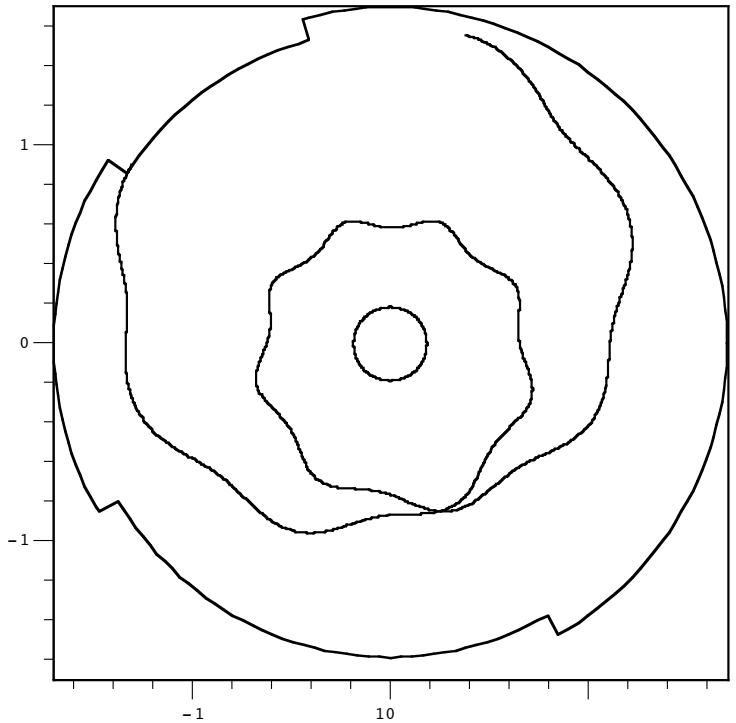
111192, t=169 ms



- Observed ρ is good match to full energy D from NBI, ρ=23 cm for E_D=91.5 keV & |B|=0.27 T

Ion orbit corresponding to peak χ



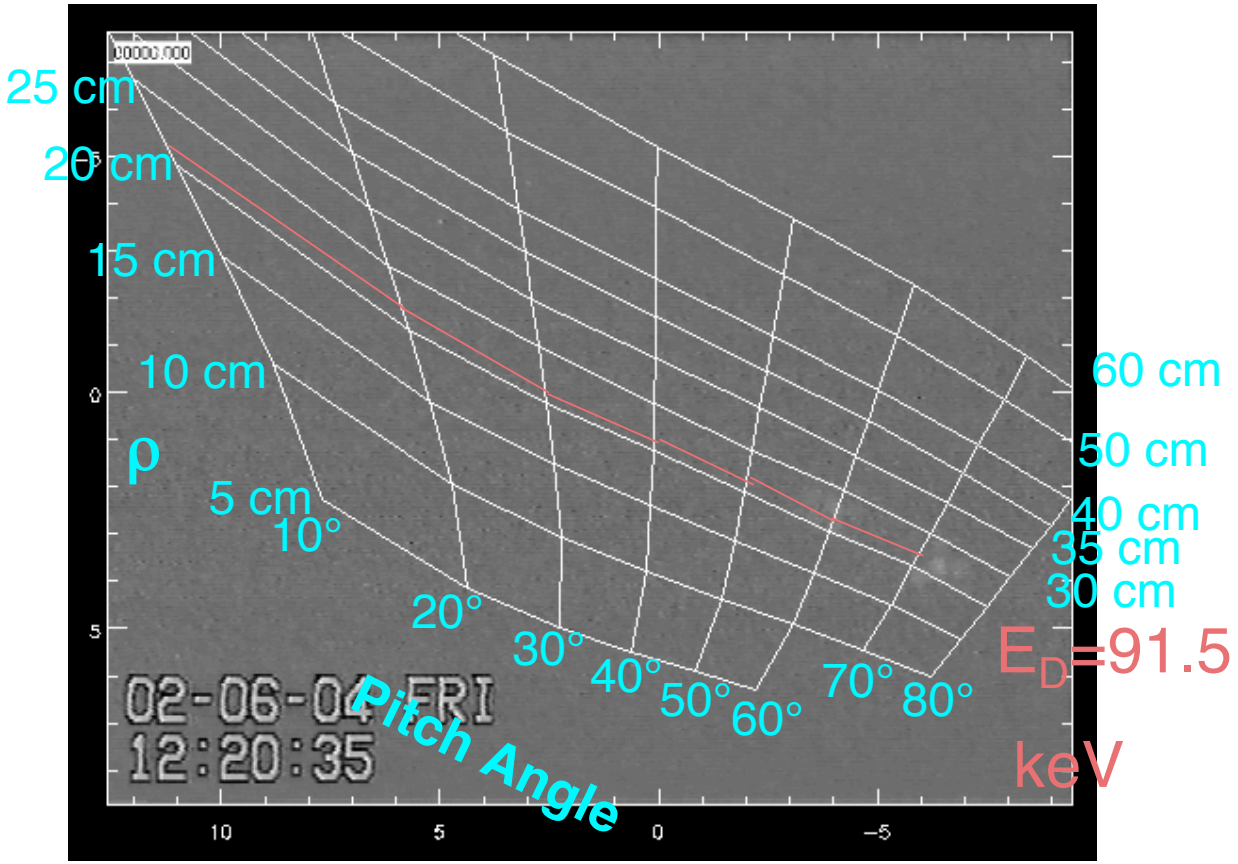



```
PPPL Lorentz ORBIT v205 for NSTX      02/08/16   11:10:00
ORBIT(S) CALCULATED ON 11/11/04
Comment Orbits to sFLIP in 111192, t=169 ms
ORBIT STRUCK LIMITER AT R= 1.584 Ph=      -574.8 Z=    .170
  3.1416   Init gyro ang     0      Time dir'n   GYRO  =    -.1439
   .0000   Init pitch ang   34/    81  IX/NX      CDPTCH=     .0000
    1.60   Detector R         1/     1  IY/NY      RIPTCH=    156.25
    -.14   Detector Z          .01   Step len (m) RMN   =       .00
 1.33046   Detector phi     100.00   Orbit len    EFFIC =3.014E-11
 1.3744    Det RZ ang       .0616   Aper sep (m) SUMEFF=4.826E-10
-1.5708    Det tor ang      .0060   Col hwidth
   1.00    Ion charge       .0010   Col hheight
   2.00    Ion mass         .0463   Det hwidth
9.150E-02  Init energy      .0010   Det hheight
0.000E+00  Init mu
```

χ=23° orbit.

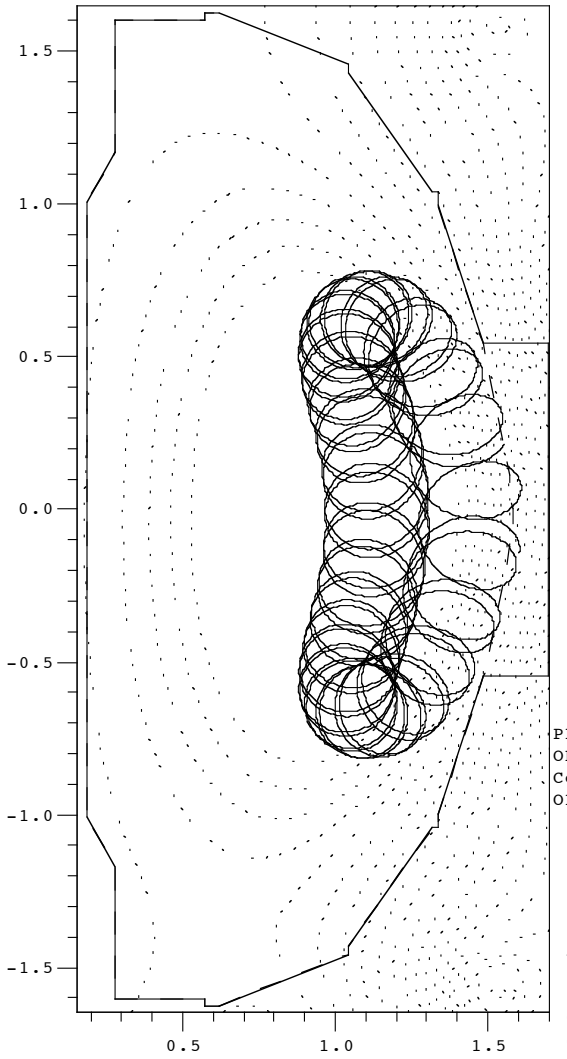
Intersects beam volume at small R

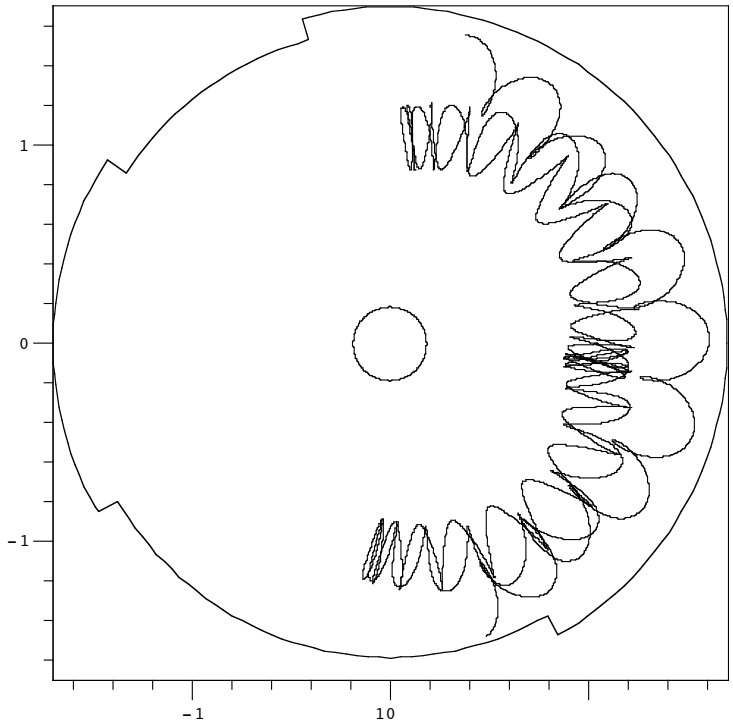
111192, t=253 ms



- Loss only at high pitch angle (~73°)

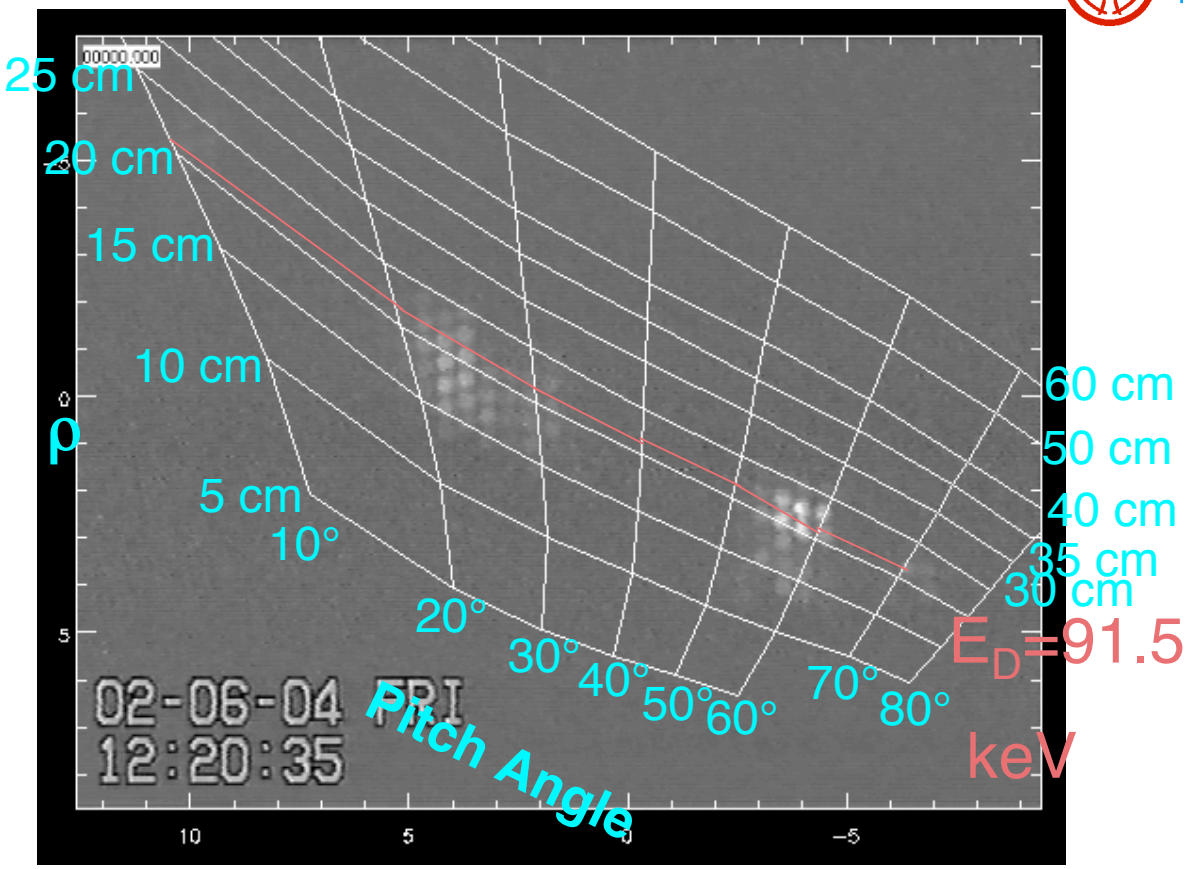
Corresponding orbit at χ=73°





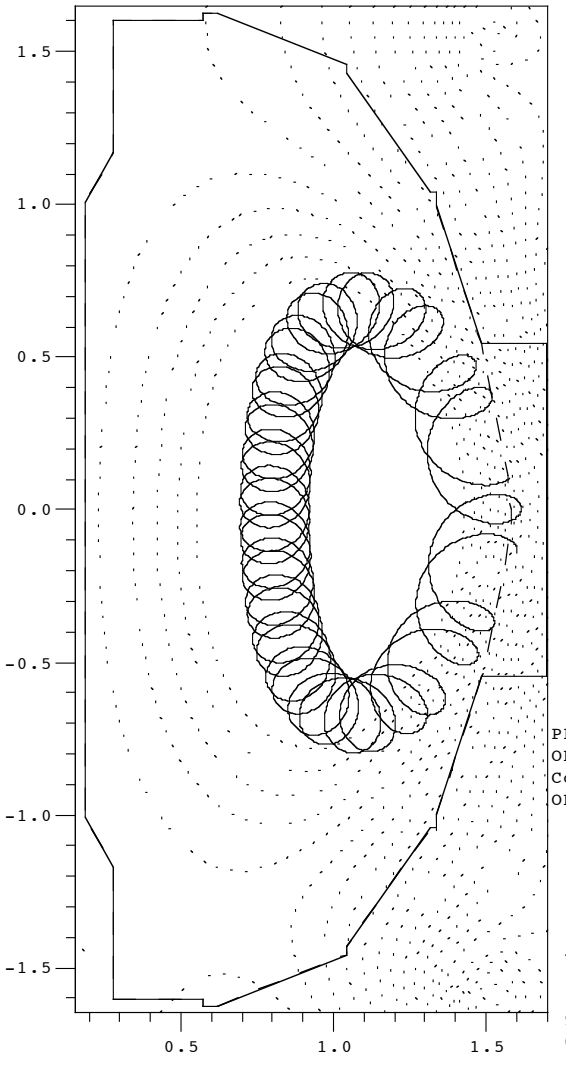

```
PPPL Lorentz ORBIT v205 for NSTX      02/08/16   11:10:00
ORBIT(S) CALCULATED ON 11/18/04
Comment Orbits to sFLIP in 111192, t=253 ms
ORBIT STRUCK LIMITER AT R= 1.554 Ph=       -71.7 Z=    .216
  3.1416   Init gyro ang     0      Time dir'n    GYRO  =     .5742
   .0000   Init pitch ang   37/    41  IX/NX      CDPTCH=     .0000
    1.60   Detector R         1/     1  IY/NY      RIPTCH=    106.98
    -.14   Detector Z          .01   Step len (m) RMN   =       .00
 1.33046   Detector phi     100.00    Orbit len   EFFIC =9.526E-09
  1.3744   Det RZ ang        .0616   Aper sep (m) SUMEFF=1.155E-07
-1.5708   Det tor ang       .0060   Col hwidth
    1.00   Ion charge        .0010   Col hheight
    2.00   Ion mass          .0463   Det hwidth
 9.150E-02   Init energy     .0010   Det hheight
 0.000E+00   Init mu
```

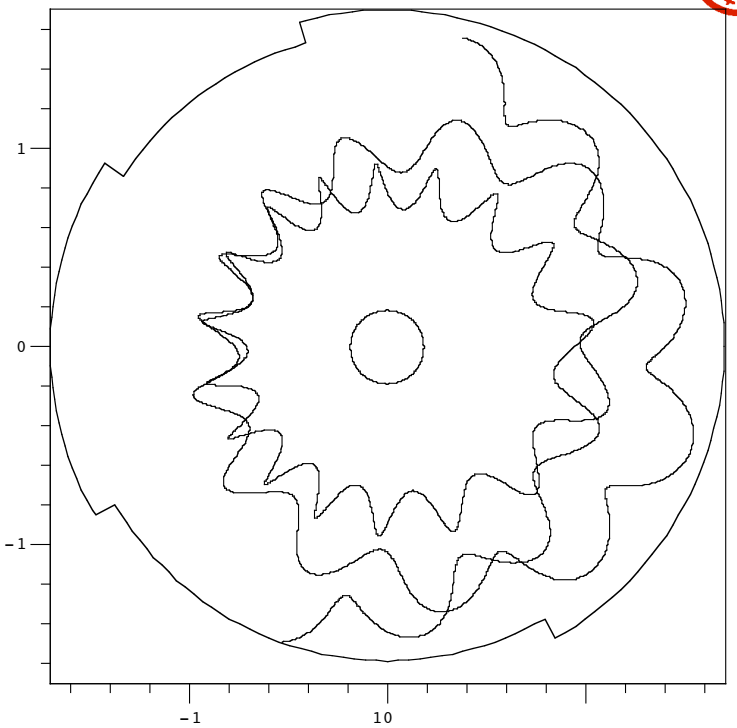
111192, t=421 ms



- During Ip rampdown: high pitch angle loss stronger & low pitch angle reappears

111192, t=421 ms, χ=57° orbit

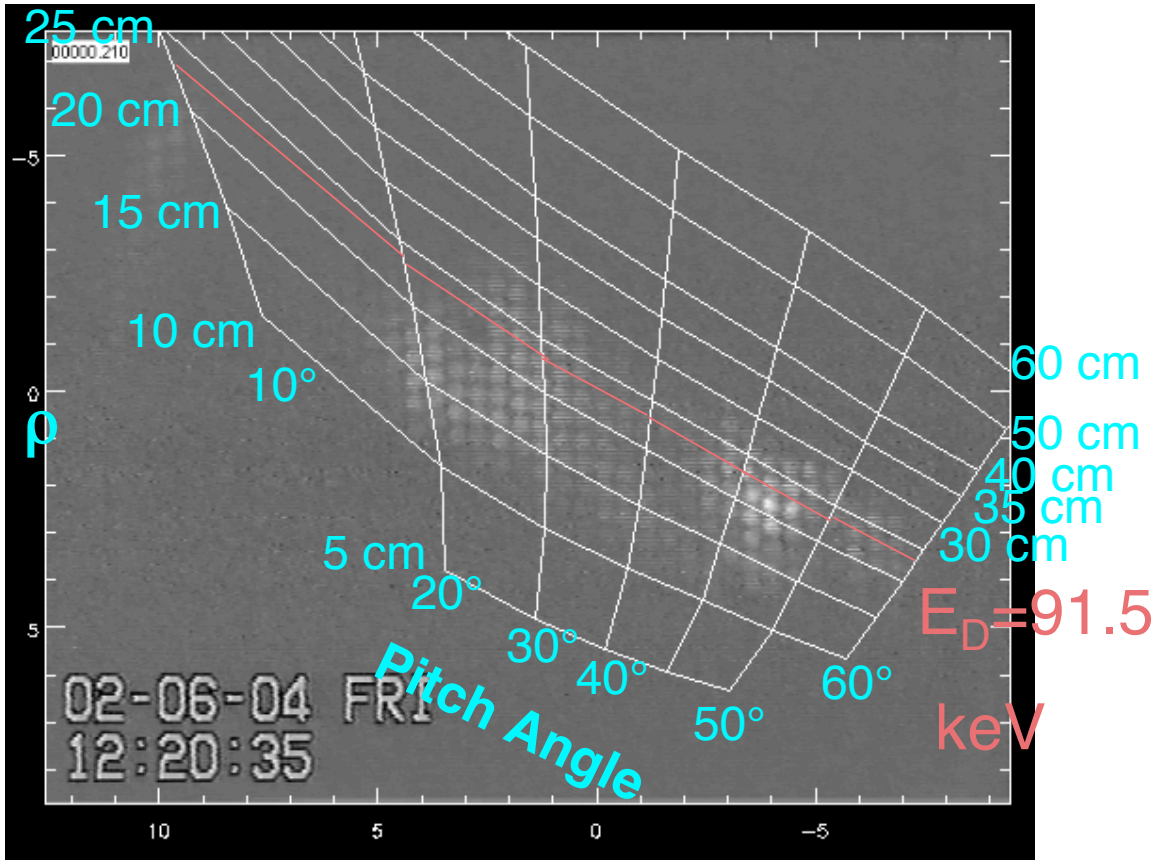





```
PPPL Lorentz ORBIT v205 for NSTX      02/08/16   11:10:00
ORBIT(S) CALCULATED ON 11/11/04
Comment Orbits to sFLIP in 111192, t=421 ms
ORBIT STRUCK LIMITER AT R= 1.577 Ph=     -829.6 Z=    .102
  3.1416   Init gyro ang     0      Time dir'n    GYRO  =     .3128
   .0000   Init pitch ang   29/    41  IX/NX      CDPTCH=     .0000
    1.60   Detector R        1/     1  IY/NY      RIPTCH=    123.78
    -.14   Detector Z          .01   Step len (m) RMN   =       .00
 1.33046   Detector phi     100.00   Orbit len    EFFIC =5.262E-09
  1.3744   Det RZ ang         .0616  Aper sep (m) SUMEFF=1.605E-08
-1.5708   Det tor ang        .0060  Col hwidth
    1.00   Ion charge         .0010  Col hheight
    2.00   Ion mass           .0463  Det hwidth
 9.150E-02   Init energy      .0010  Det hheight
 0.000E+00   Init mu
```

Appears to originate near outer edge

111192, t=487 ms



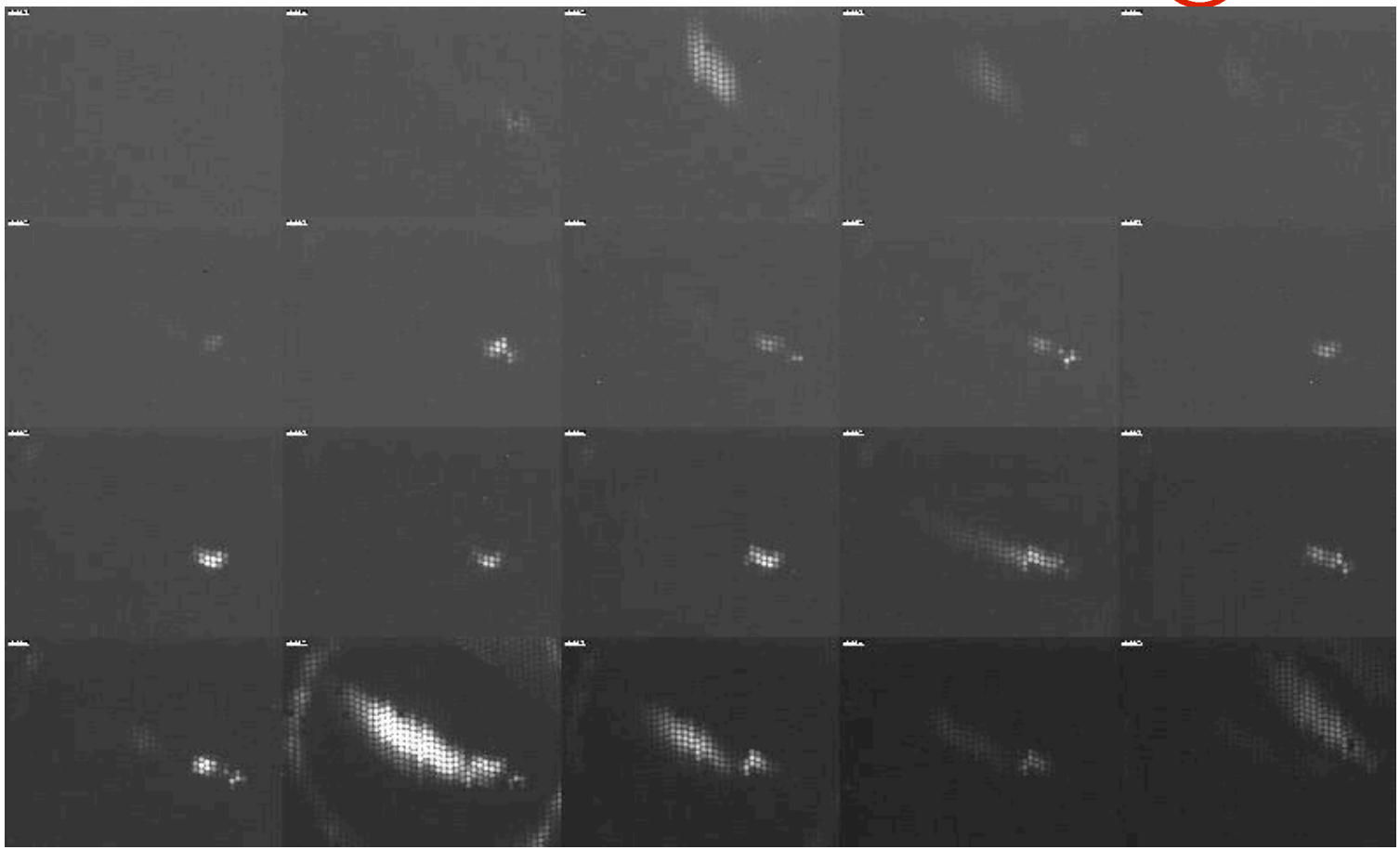
- Losses cover wider range of χ

Initial observations appear consistent with prompt loss

- The orbits shown here appear to be ones that are populated directly by NB deposition in the plasma. Requires:
  - Velocity at some point on orbit is horizontal and aligned with beam direction
  - Birth point is within beam volume
- More extensive calculations are desirable to confirm this interpretation

PPPL PRINCETON PLASMA PHYSICS LABORATORY

MHD affects high χ loss



112232

- Bright, wide-χ loss near end due to RE

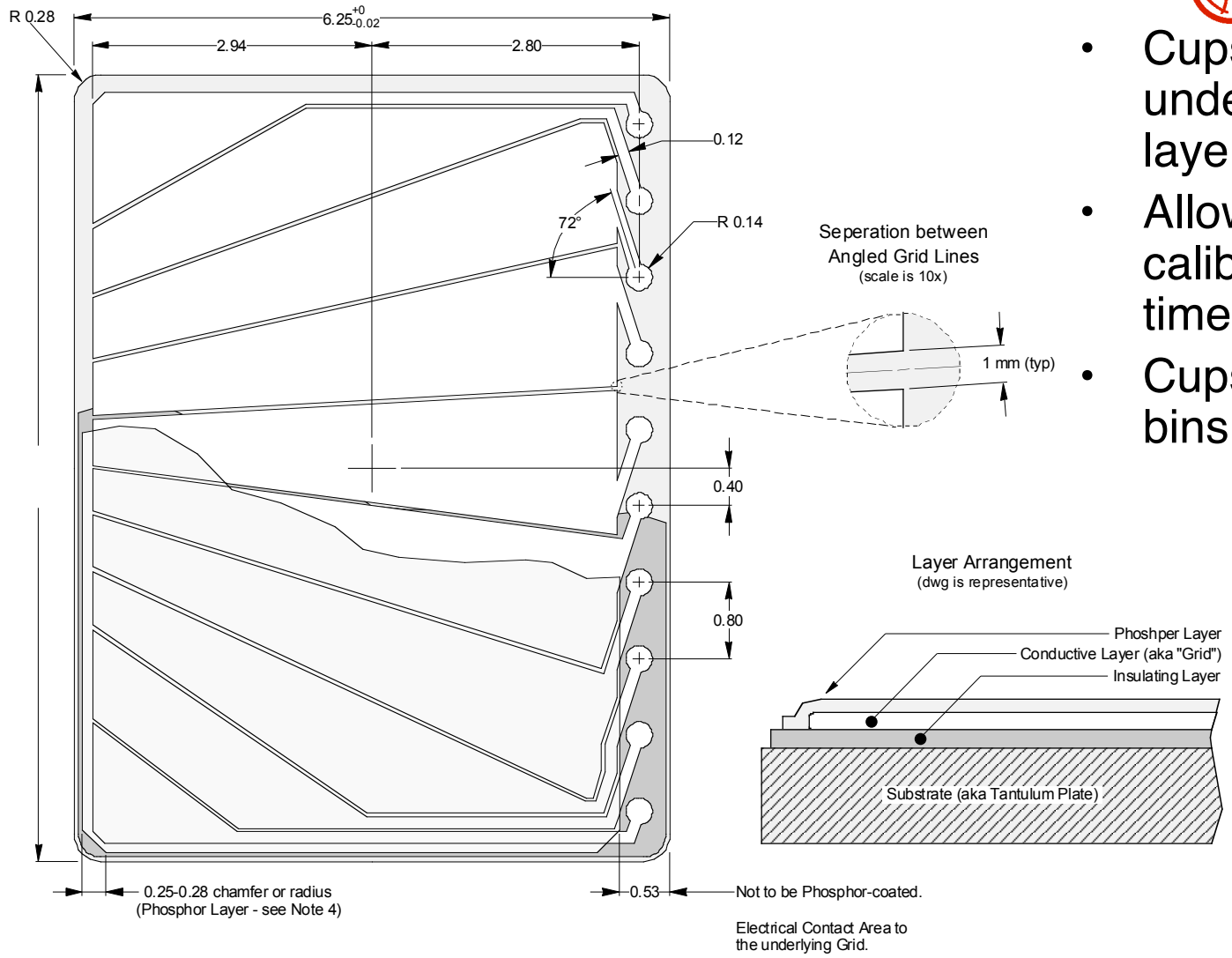
Summary

- Beam ion losses resolved in E & χ being measured routinely
- Typical loss signature is:
  - Broad range of χ early, at low n_e
  - High χ only later at higher n_e, sometimes modulated by MHD
- Preliminary analysis suggests dominant losses (aside from MHD) are prompt losses

Future plans

- Automate mapping of data to (E, χ) space
- Investigate modes of loss and compare with models, esp. MHD-related losses
- Improve Faraday cup strip instrumentation for absolute calibration and faster time response

Scintillator plate also contains embedded Faraday cups



- Cups formed by undercoated aluminum layer
- Allows rapid absolute calibration & gives fast time response
- Cups matched to ~10° bins in pitch angle

PPPL PRINCETON PLASMA PHYSICS LABORATORY