Influence of admixtures, external magnetic field and neon plasma sheath with deuterium gas-puff on the neutron production in plasma focus discharges

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Outline

Experiments and results provided on PF-1000 in 2012-13

1. Influence of the tungsten anode face
   on the neutron production and X-ray radiation

2. Influence of the external poloidal magnetic field on the neutron production and X-ray radiation

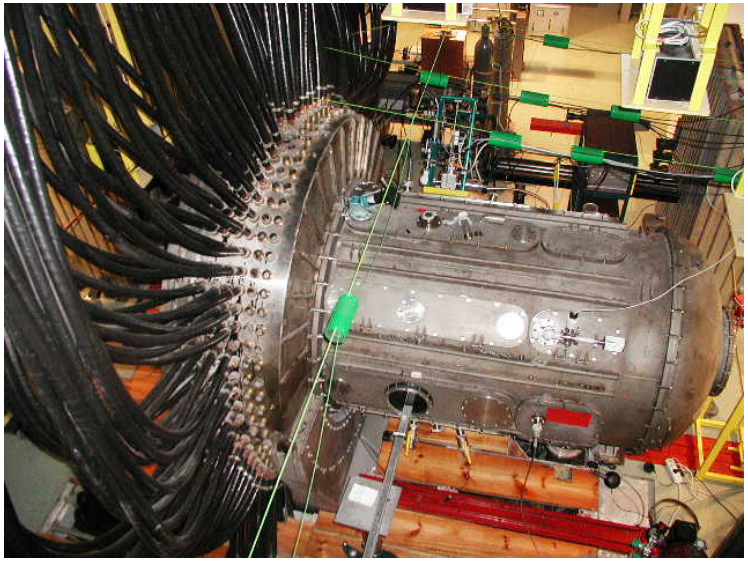
3. Compression of the deuterium from the gas-puff in the anode by the neon plasma sheath

PF-1000 IPPLM Warsaw, Poland

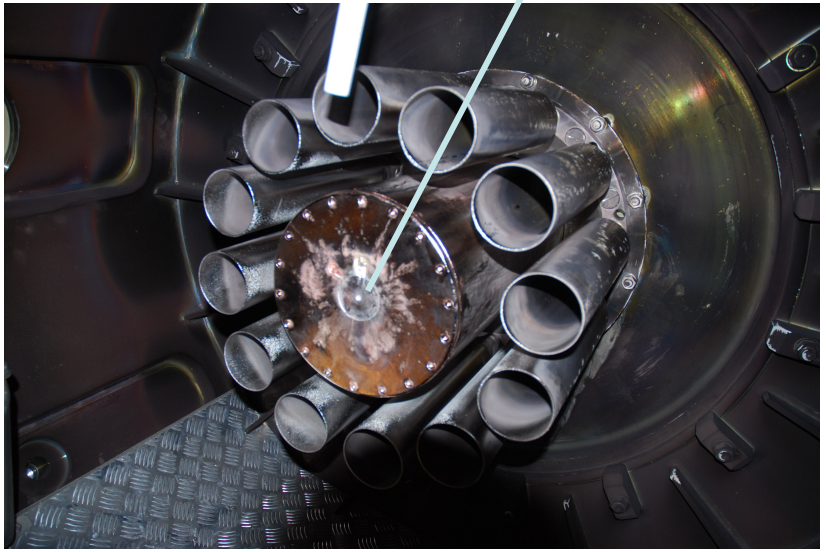
2 MA, 400 kJ, D-D reaction, D_2 gas

neutron yield 10^{10}-10^{12} , horizontal position of discharge axis

facility



electrode system tungsten plate



the intense neutron source

Scintillation detectors of neutrons in axial and radial directions

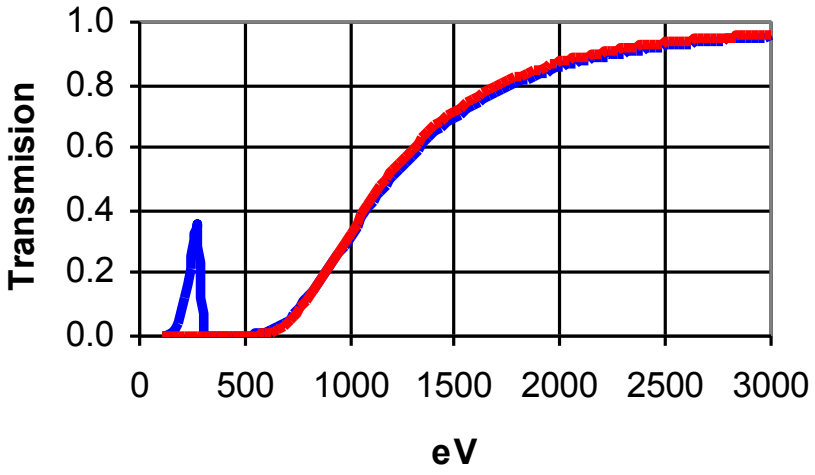
Mach-Zender interferometer, 16 beams, 527 nm, 1 ns during 220 ns

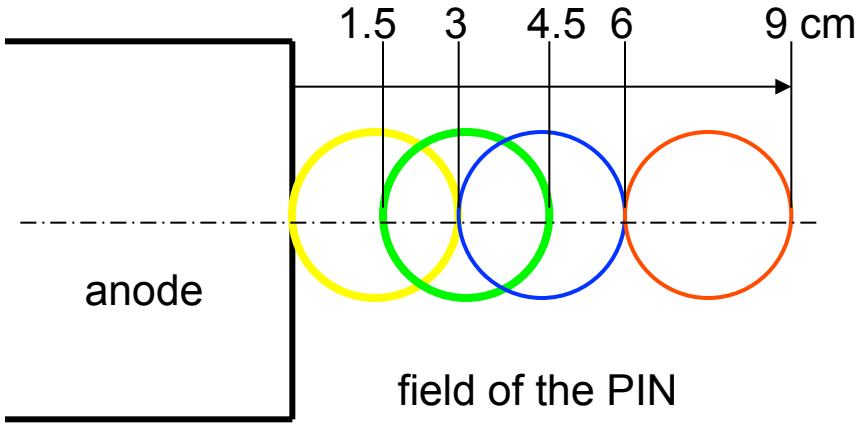
signals of U,I,dI,

Soft X-frames + MCP+CCD

4 Soft X PIN

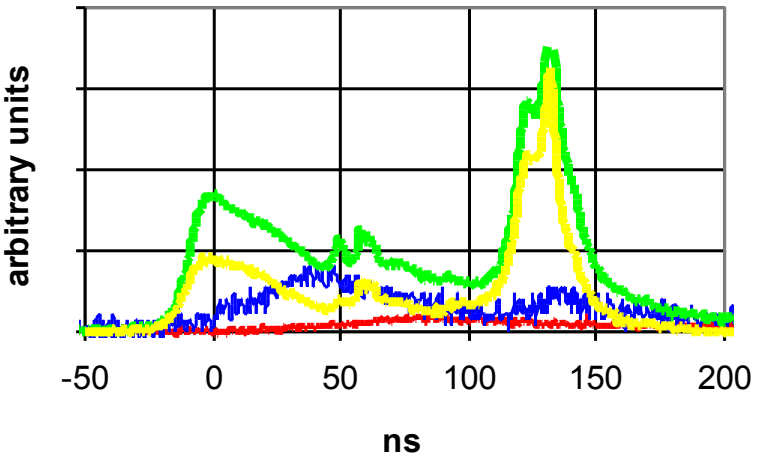
Soft X-ray diagnostics





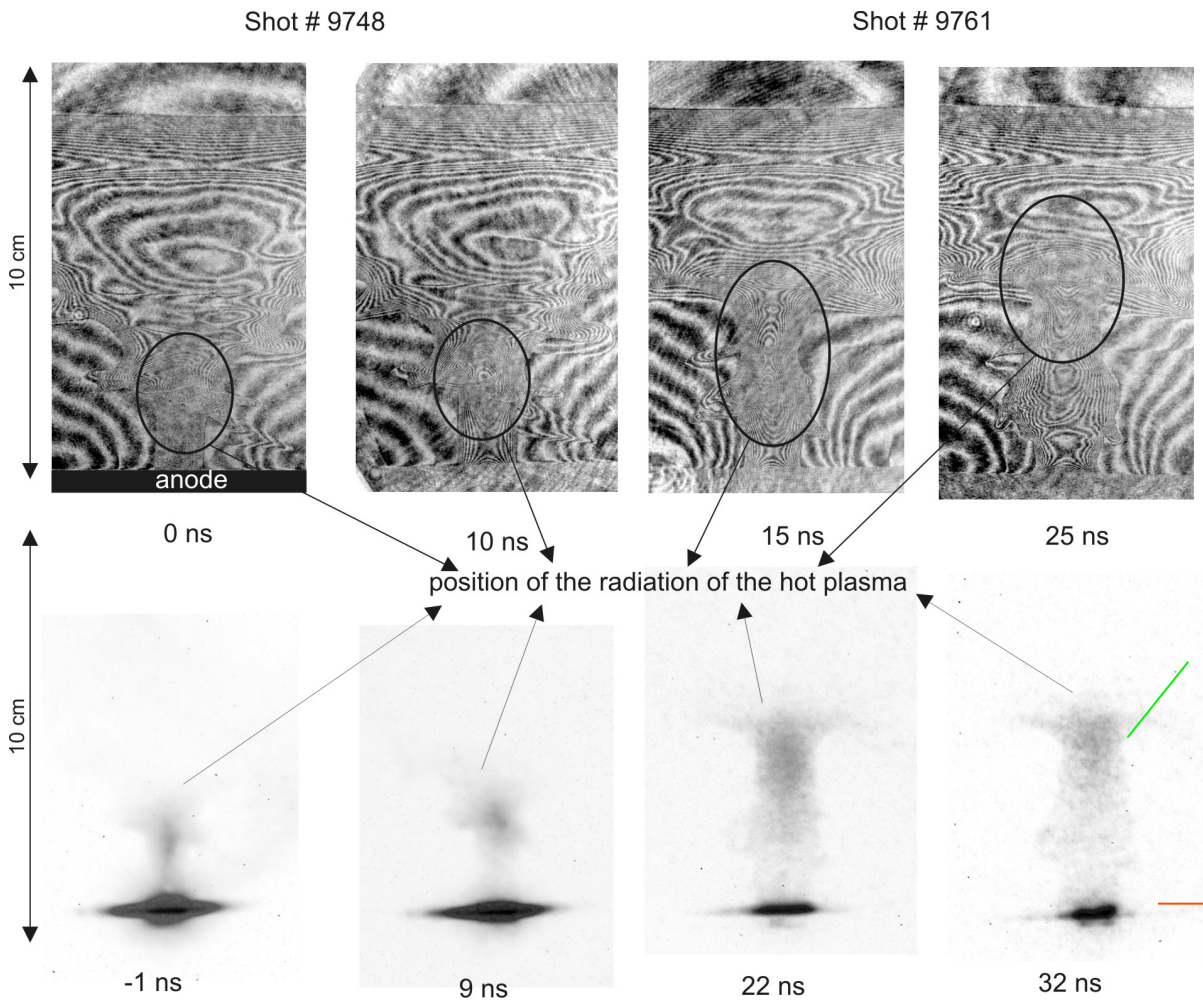
field of the PIN

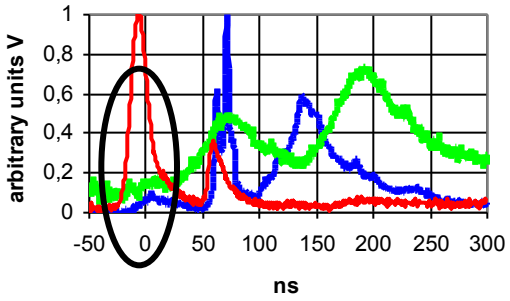
X-frames - transmission of polystyrene 5μm
PIN detectors Be 10 μm filters
Window 150-300 eV
The same sensitivity 0.7-5 keV



sensitivity of PIN

Tungsten anode plate - first neutron pulse



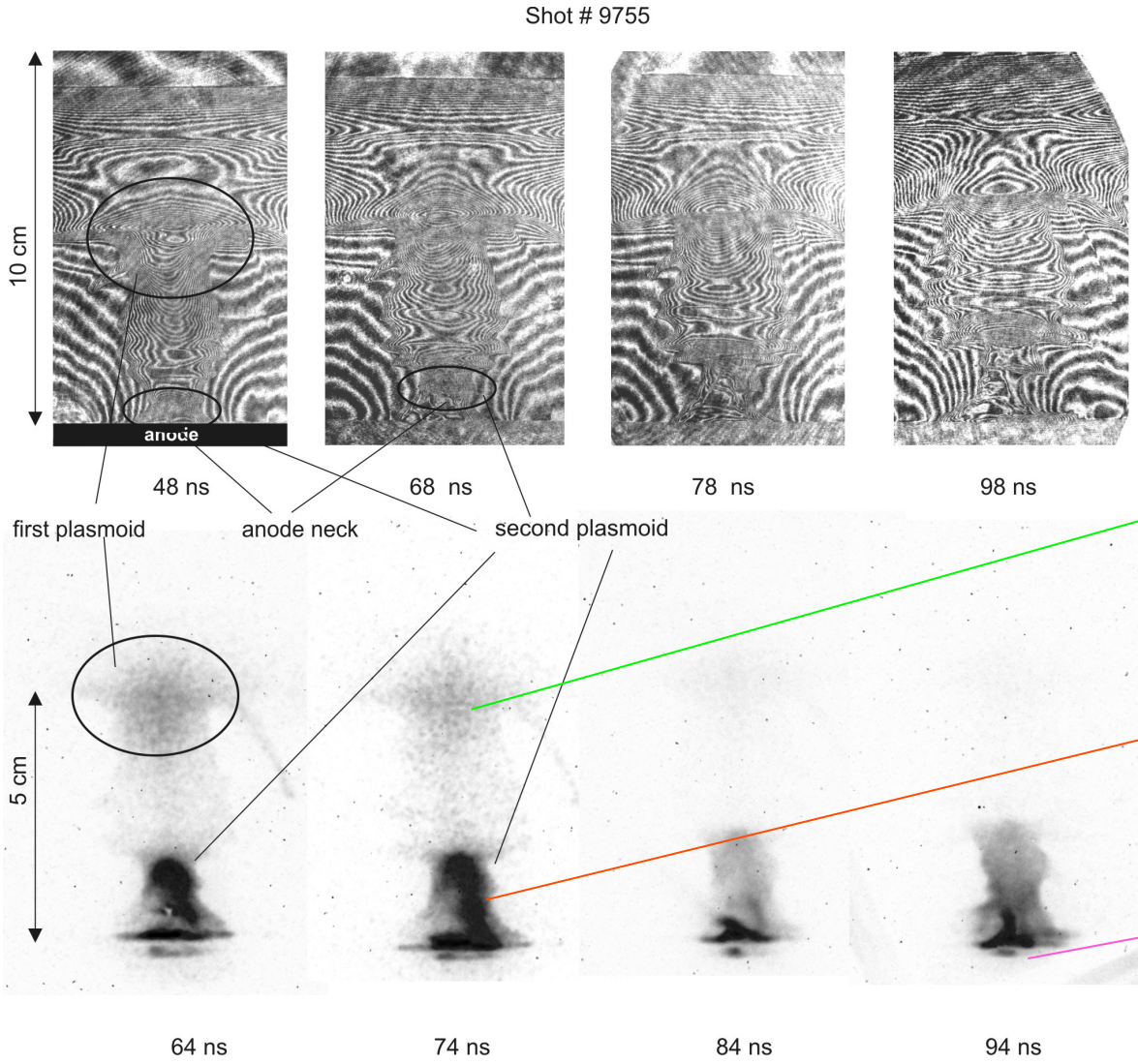


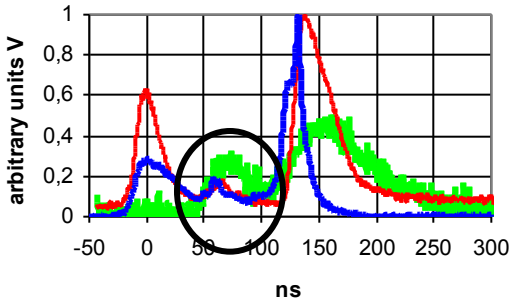
Signals SXR, HXR, neutrons
Time 0 - current derivative dip

Bremsstrahlung from
the deuterium plasmoid

Recombination
from the anode

Evolution of anode constriction in plasma with tungsten





Signals SXR, HXR, neutrons

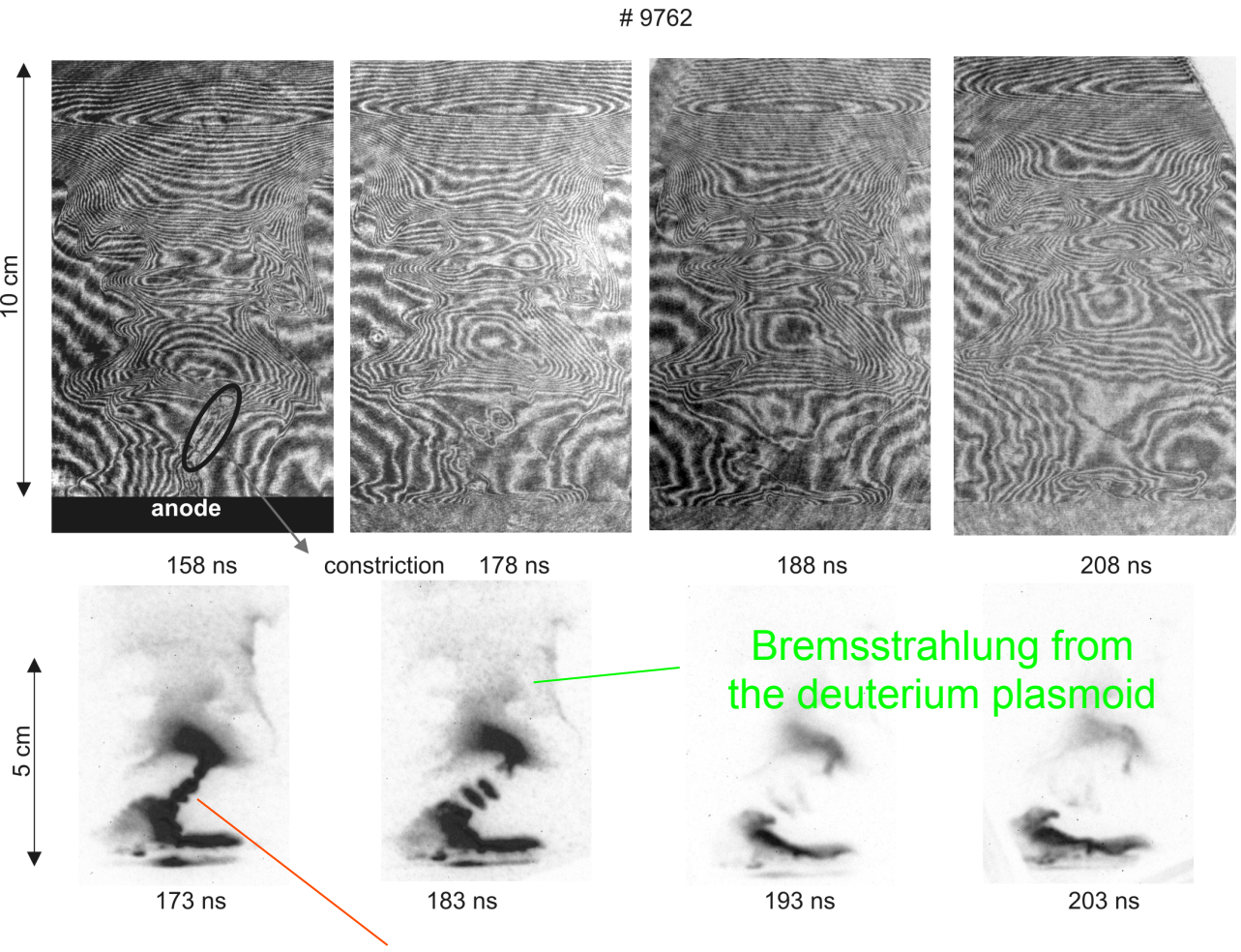
Bremsstrahlung from the deuterium plasmoid

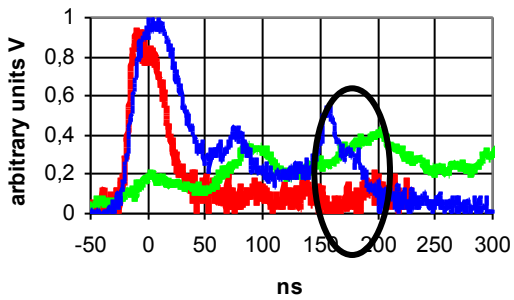
Recombination from the anode constriction

Recombination from the anode

Transport of tungsten into plasma column due to constriction „wall instability“ Bride R D et al 2013 *Phys. Plasmas* **20**, 059309

Evolution of constriction in plasma with tungsten



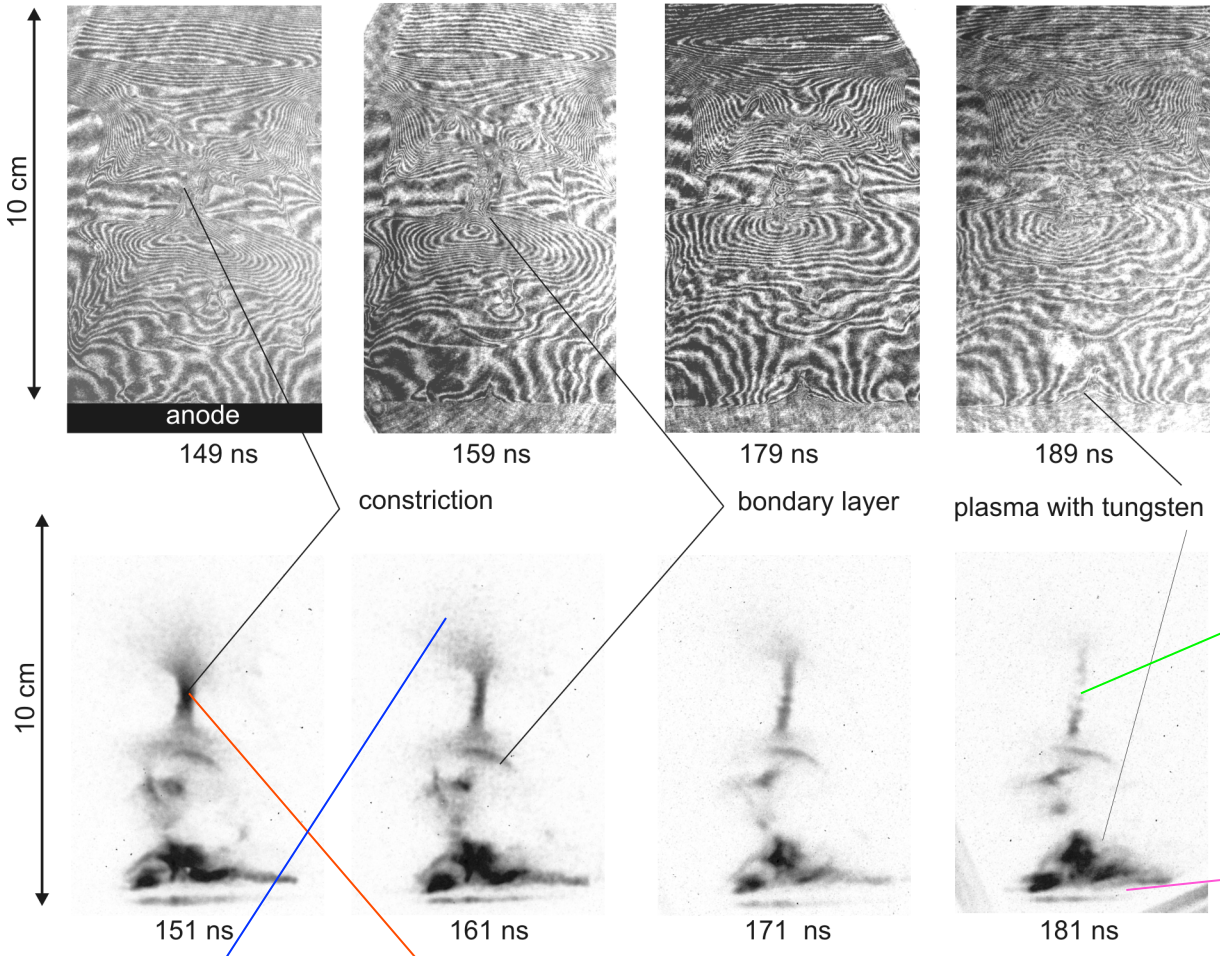


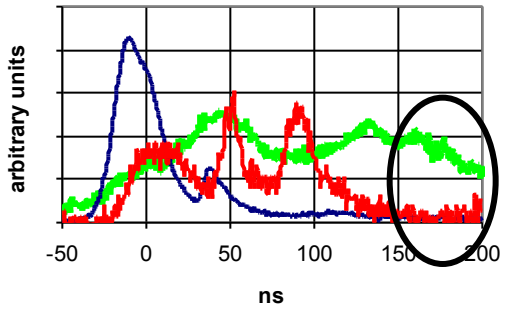
Signals SXR, HXR, neutrons

Emission of the region of the decay of constriction and of the ejected plasma

Evolution of constriction in plasma without tungsten

Shot # 9754





Signals SXR, HXR, neutrons

Bremsstrahlung from the deuterium plasmoid

Recombination from the anode

Hot plasma in the constriction without tungsten

Colder plama in region of ejected plasma

Power of recombination and bremsstrahlung

Artsimovich L A, Sagdeev R Z 1979 *Plasma Physics for Physicists*; Moscow - Atomizdat

recombination $$R_R = 5\times10^{-33}\, z_W^4 n_e n_W T_e^{-1/2}$$

bremstrahlung $$R_B = 1.5\times10^{-38}\, z_D^2 n_e n_D T_e^{+1/2}$$

ratio $$\frac{R_R}{R_B} = 3.3\times10^{5}\, \frac{z_W^4}{z_D^2}\, \frac{n_W}{n_D}\, T_e^{-1}$$

[m^3, K]

Deuterium bremsstrahlung dominates at Te≥ 30 eV
Recombination of tungsten dominates for 1%, Te 30-100 eV, z ≈ 3-6

Conclusions

In pure deuterium dominates bremsstrahlung namely in the last phase of the existence of the compact constriction

Recombination dominates in the region with tungsten during evolution of instabilities (2 times higher power in comparison with bremstrahlung in pure deuterium Estimations 1% of W, $z \approx 3\text{-}4$

Recombination increases during decay of the constriction – analogy of hot spots at higher z

Decrease of the neutron yield to 40% and decrease of the energy of fast deuterons producing neutrons to 80%

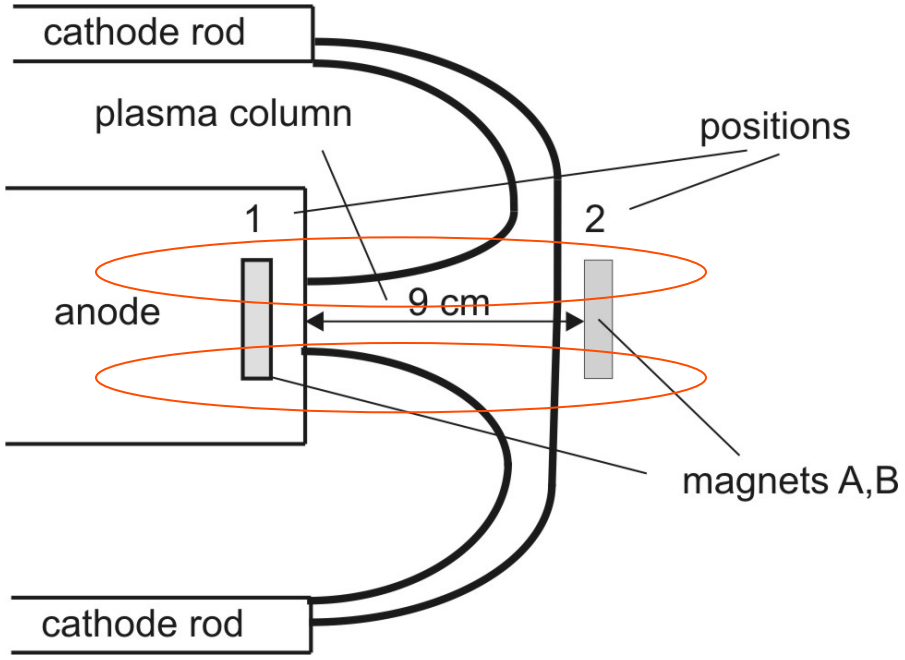
At presents of tungsten – decrease of implosion velocity of constriction from 2.5×10^5 m/s to 1-2 $\times10^5$ m/s

At this implosion, energy of 10-40 keV delivered to the tungsten ions, (whiles to the D ions below 0.5 keV).

Accepted for publication in PPCF

Influence of the external poloidal magnetic field on the neutron production and X-ray radiation

Experiments of M.Paduch and E. Zielinska, IPPLM Warsaw



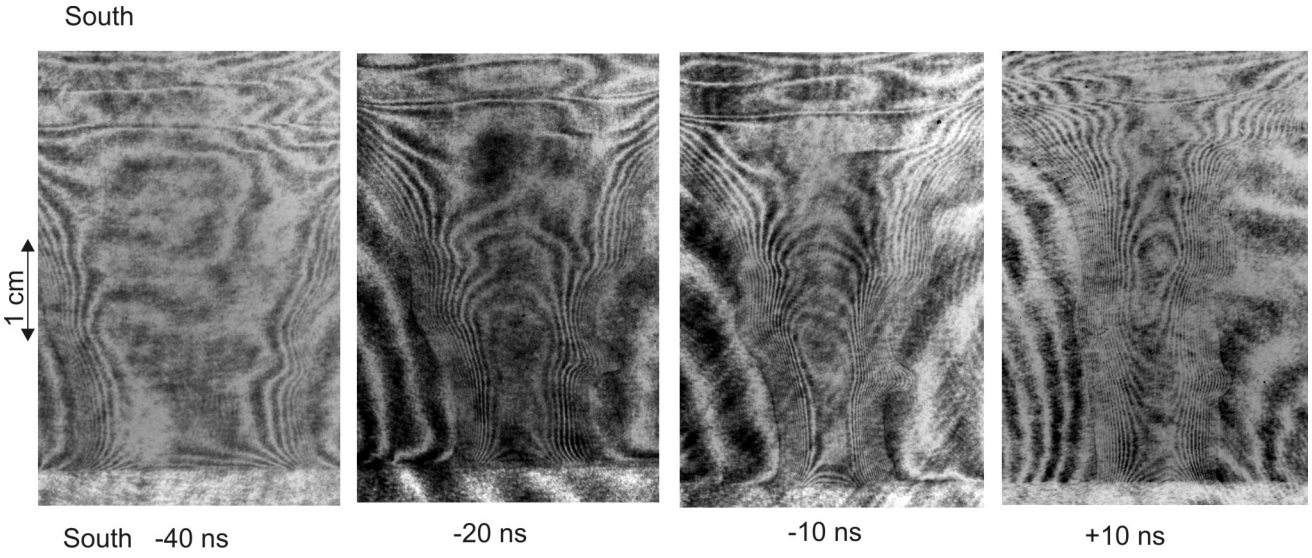
Poloidal magnetic field
B ≈ 40-70 mT

Compression to the 5-10 T similar as the Bz magnetic field measured by magnetic probes

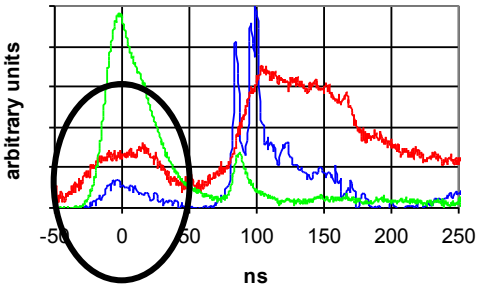
Krauz V I et al 2012 *Plasma Phys. Cntrol. Fusion* **54,** 025010
Krauz V I et al 2012 Europhys. Lell. **98**, 45001

First neutron pulse

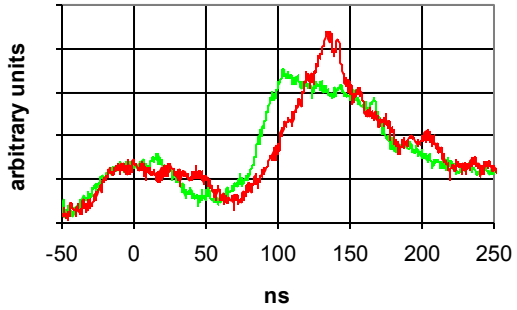
Shot # 9708



Interferograms at the time of the first neutron pulse



Signals of PIN, HXR and neutrons were registered side-on. Neutrons were temporally shifted to the time of the neutron production using the time-of-flight calculation supposing the neutron energy of 2.45 MeV



neutron signals registered in 7 m side-on and upstream

Results

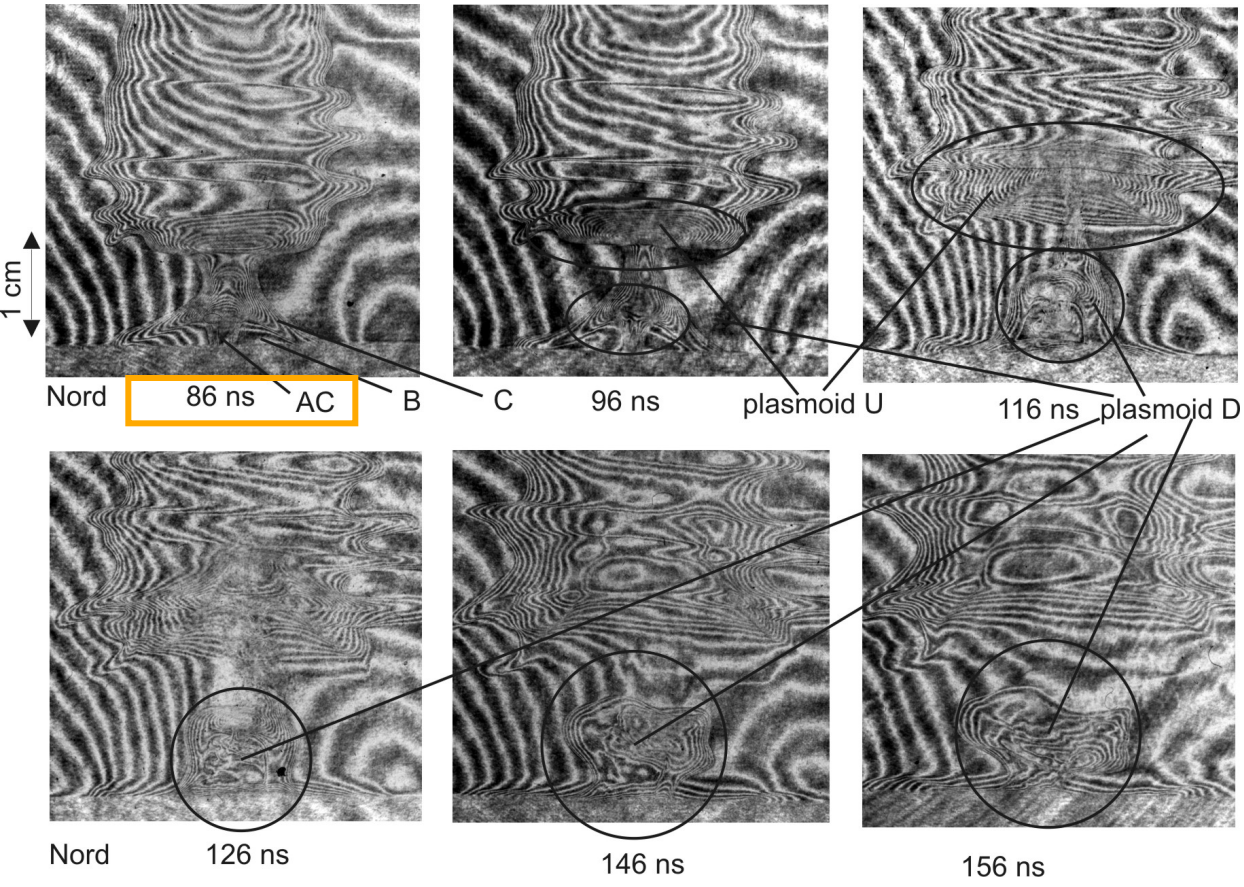
Increase of stability of pinch column

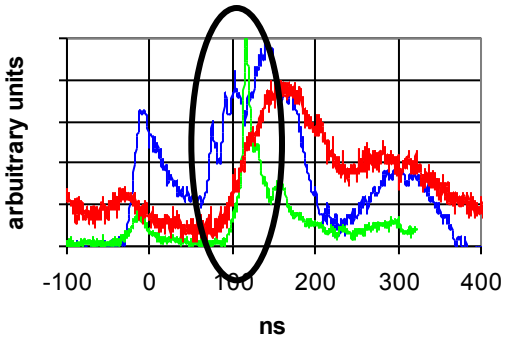
Dominant beam-target mechanism in first neutron pulse

(Ed(z)≈100-140 keV, Ed(r) ≈ 25 keV

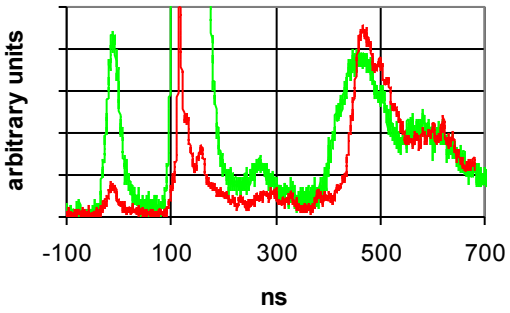
Magnet in anode – evolution of instability

Shot # 9729





Signals of PIN, HXR and neutrons



HXRs and neutrons registered in 7 m side-on and upstream

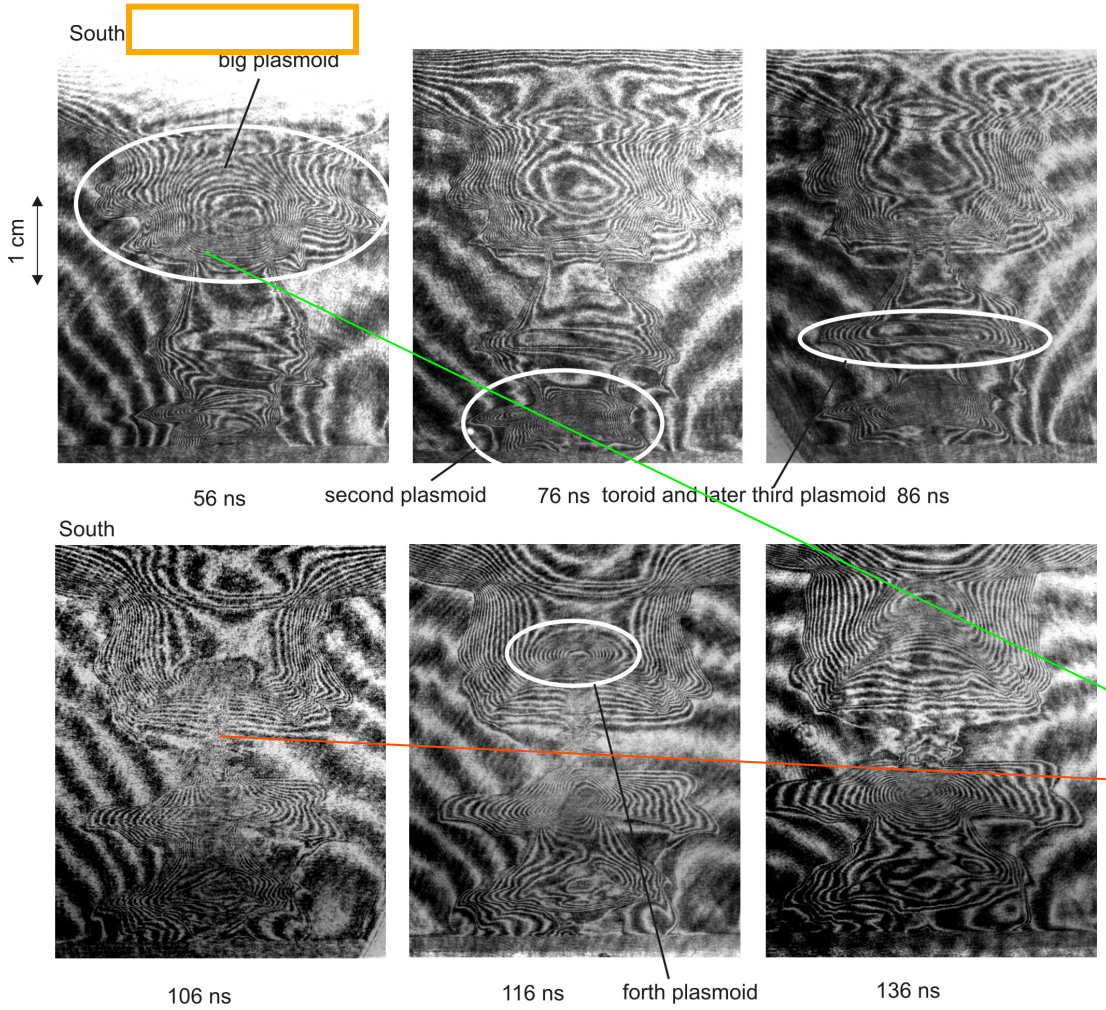
Conclusions:

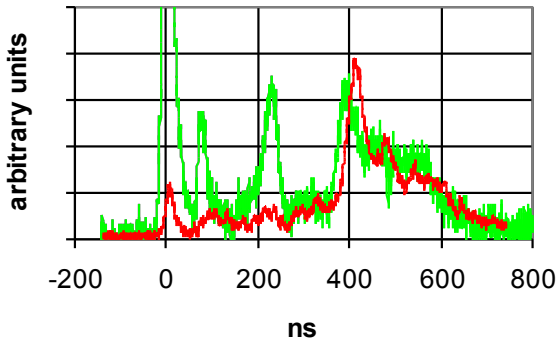
Decrease of the neutron yield to 40%

Symmetrical column, stable structures

Magnet at end of column – formation of the big plasmoid

Shot # 9716





HXRs and neutrons registered in 7 m side-on and upstream

Interferograms with big plasmoid and long constriction

This position of the magnet support formation of the stable and dense target for higher neutron production

Conclusions

At PF-1000 the external poloidal $B_p \approx$ 40-70 mT was compressed to the value of 5-8 T, the same value measured by magnetic probes

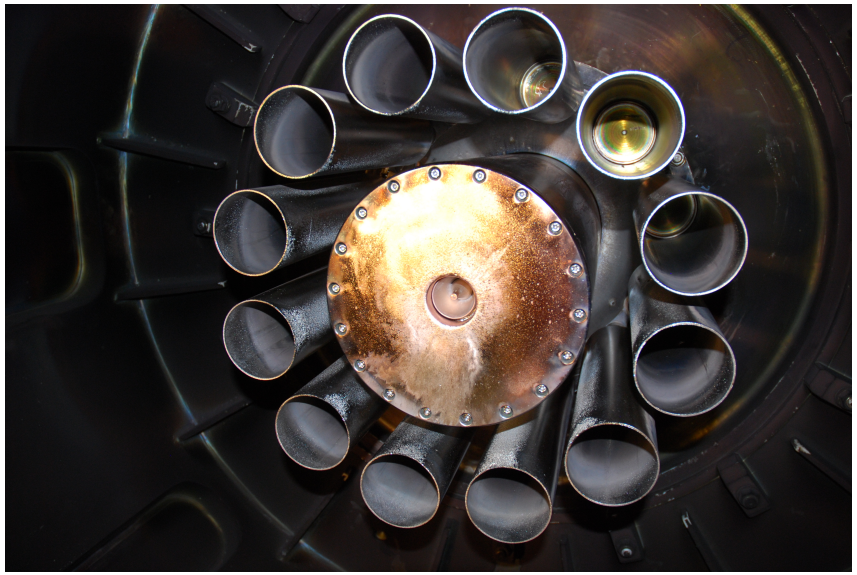
Magnetic pressure Bp ≈ 1.4×10^7 Pa …. 7% of the Bφ pressure

Stabilization role:
(i) Decrease of the tearing of Bp
(ii) Depress of the instabilities on the surface of the plasma column
(iii) Increase of the symmetry of the column
(iv) Increase of the length and time-of life of the constriction

external Bp dissipates from the column after 100-150 ns

Possible utilizing:
(i) Active influence of the optimal internal ratio of Bp/Bt
(ii) Formation of the stable and dense target for deuteron beams to produce higher neutron yield

Implosion of the deuterium gas-puff by the neon plasma sheath February 2012



Anode ∅ 23 cm with central nozzle

Nozzle ∅ 4 cm

Experiments:

(i) Deuterium plasma sheath 1.5 torr, 32 μg/cm

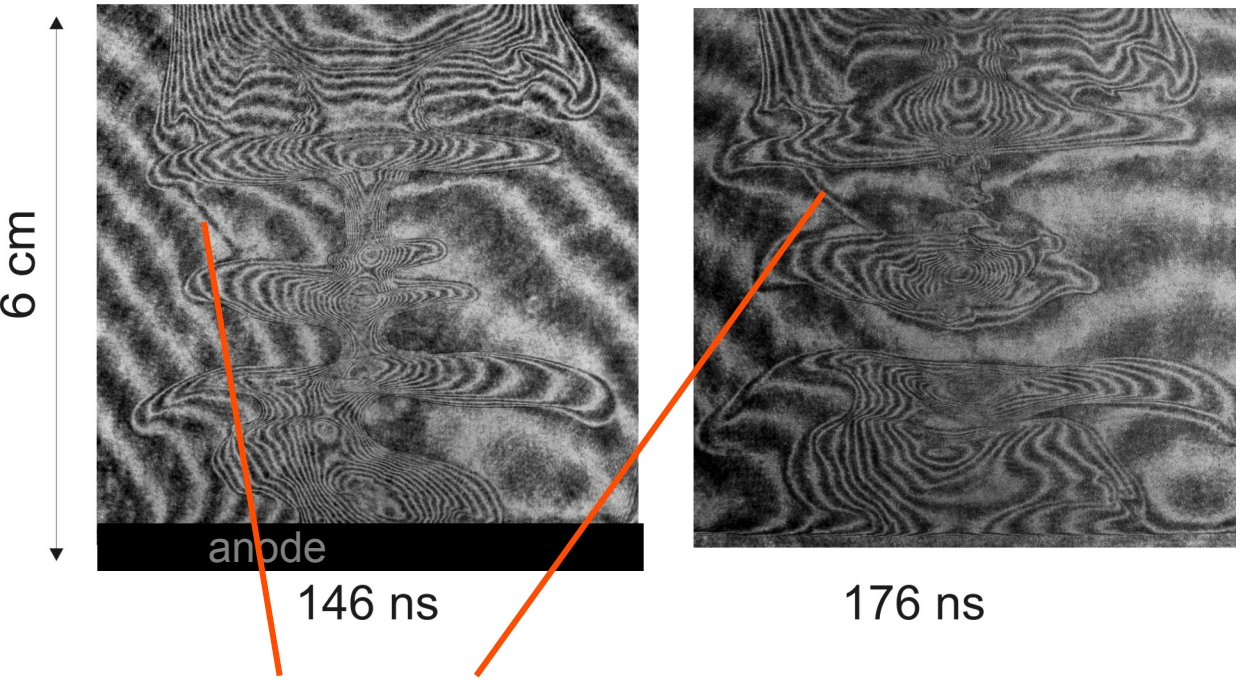
(ii) Deuterium plasma sheath 32 μg/cm + deuterium jet 5-10 μg/cm

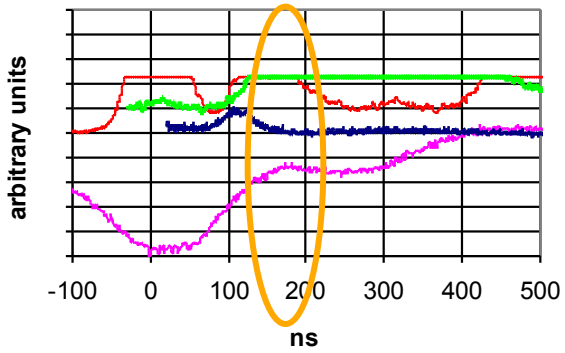
(iii) Neon plasma sheath 0.4-0.6 torr, 45 - 65 μg/cm

(iv) Neon plasma sheath 65 μg/cm + deuterium jet 5-10 μg/cm

(i) Deuterium plasma sheath 1.5 torr

Shot 9874





SXR, HXR, neutron, dI/dt

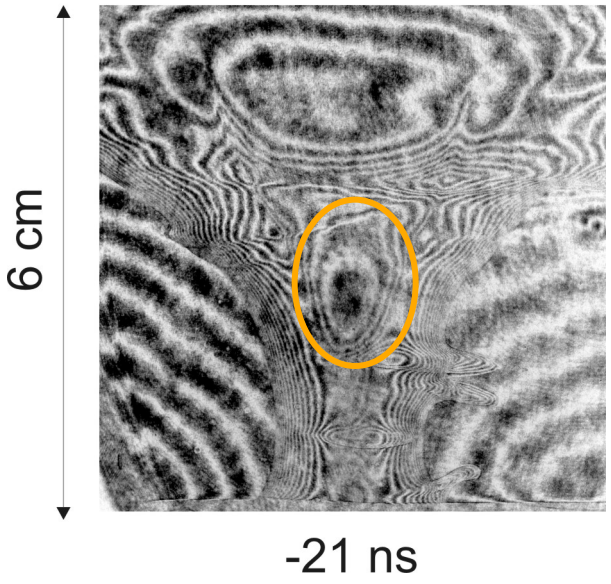
Dominant HXR and neutron pulse

Breakdown in the final phase of implosion

Neutron yield 3.3×10^{10},
Length of the pinch 7 cm
Mean energy of deuterons producing neutrons downstream 160 keV
side-on 70 keV
$n_e \approx n_i$: constriction 3.7×10^{24} cm^{-3}, plasmoid 1.1×10^{24} cm^{-3}; $v \approx 1.6\times10^{5}$m/s

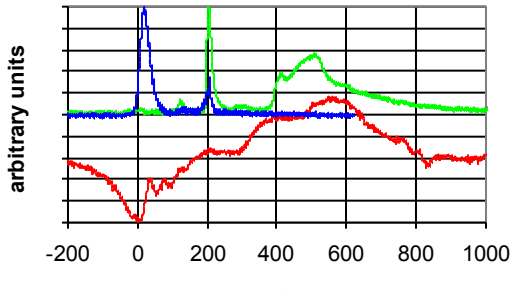
(ii) Deuterium plasma sheath + deuterium jet

Shot 9880

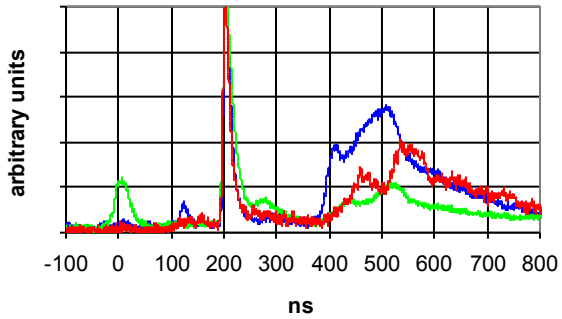


-21 ns

Possibility of estimation of mass of D from the nozzle ≈ 18%

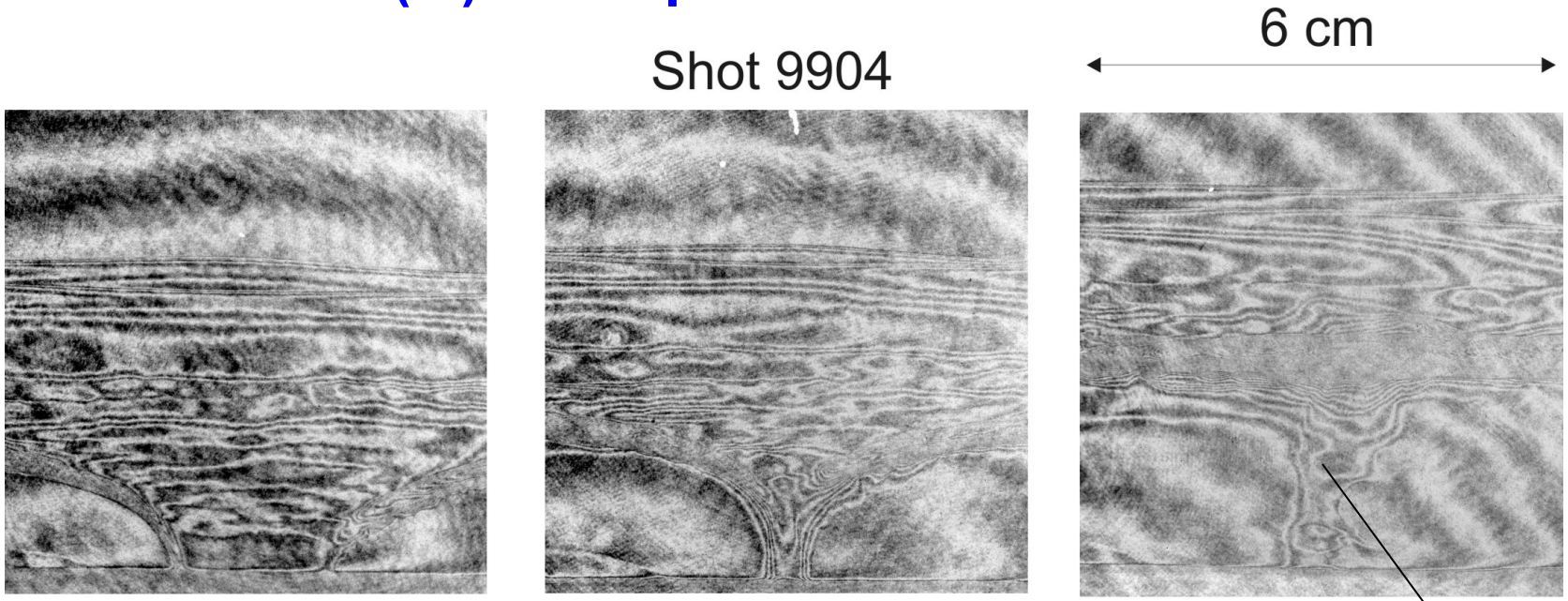


SXR, HXR, neutron, dI/dt

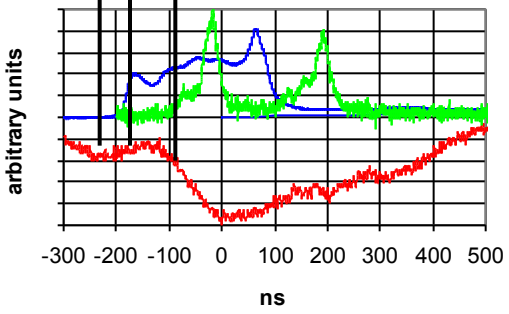


Neutron signals down, side-on and up
⇒Ed(z) ≈ 160 keV, Ed(r) ≈ 20 keV

(iii) Neon plasma sheath 0.4 torr



ne ≈ 7×10^{23} m^{-3}



SXR, HXR, dI/dt

Pinch phase ~ 200 ns before HXR and dI dip, n_e ≈1.6×10^{24} m^{-3}

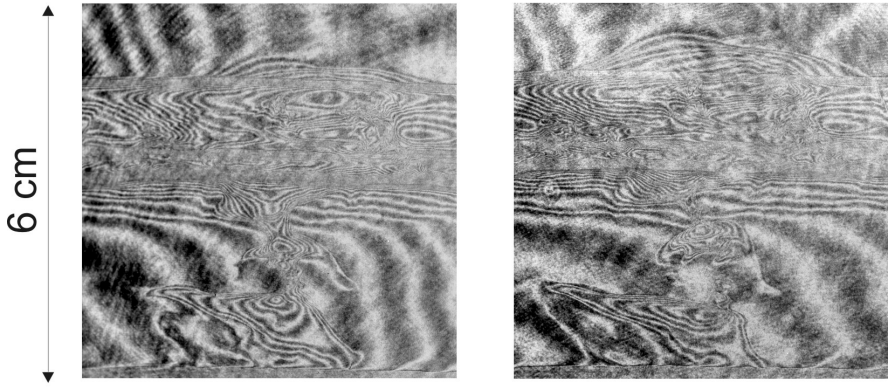
Duration of the stagnation 200 ns

Length of the pinch 3 cm

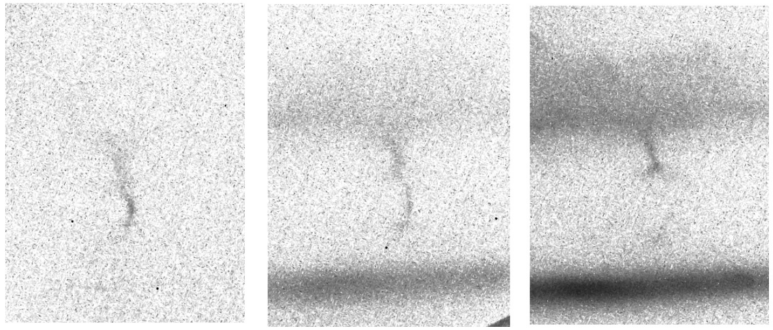
Implosion velocity 2.25×10^5 m/s; E(Ne) ≈ 2-3 keV

(iv) Neon plasma sheath + deuterium jet

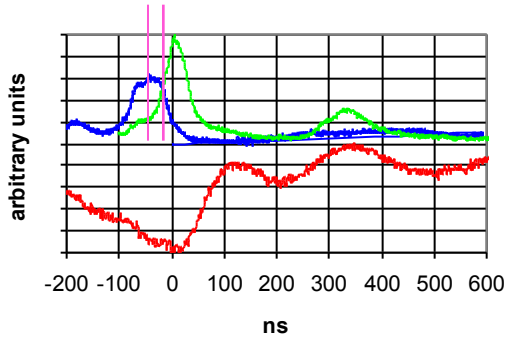
Shot 9903



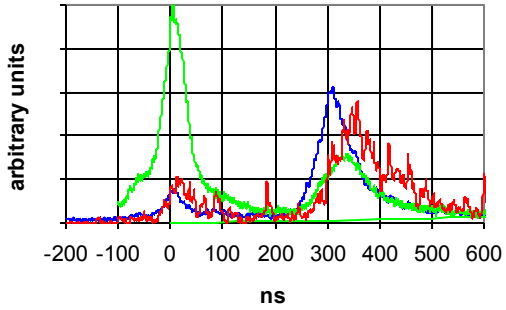
-54 ns -34 ns



-50 ns -40 ns -30 ns



SXR, HXR, dI/dt



neutron signals down, side, up

NY 1×10^{10}, beam-target, Ed(z) ≈ 80 keV, Ed(r) ≈ 20 keV
Neutron production ≈ 200 ns after pinch at ne ≈ 2×10^{24} m^{-3}.

Comparisson of parameters in D and Ne

parameter	D/ 1.5torr	Ne/0.6 torr	Ne + D
Maximum of current [MA]	2.13	2.18	2.20
Implosion velocity of plasma sheath [$\times 10^5$ m/s]	2.4	2.2	2.2
Temporal position of the pinch toward the dip [ns]	0	-200±30	-200±30
n_e in pinch [$\times 10^{24}$ m^{-3}]	4.1	2.1	3.1
Current in pinch	1.44 ±0.1	1.69 ±0.1	1.66 ±0.1
Voltage peak	35.3	19.7	25
SXR FWHM [ns]	46	240	180
Total energy SXR Be 10 μm ≥ 700 eV [J]	1.1	2.8	1.0
Length of the column [cm]	6-8	3.2-3.4	3 cm
Ed(z)/Ed(r)	140/60		120/30
Implosion velocity of constriction [$\times 10^5$ m/s]	1.6		0.6
Energy of ions during constriction implosion [keV]	0.27		1.35

Thank you for your attention