Detection of Energetic Particles in Pinch Plasma

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- introduction
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- PF-3 in KI Moscow
- conclusions

Introduction

energy ditribution of particles in pinch –

- Planckian, temperature 40-50 eV
- hot spots temperature (200 eV-keV) a few %
- fast electrons, fast ions, hard x-rays (energy above100 keV), 10^{-6}

aim of discharges with deuterium – study of:

- neutron production from D-D reaction (2.45 MeV) - energy distribution and isotropy
- hard x-rays, fast electrons and deuterons emission (above100 keV),
- process of generation of high energy particles and radiation
- thermonuclear / beam-target mechanism of generation

aim of discharges with fibers and wires –

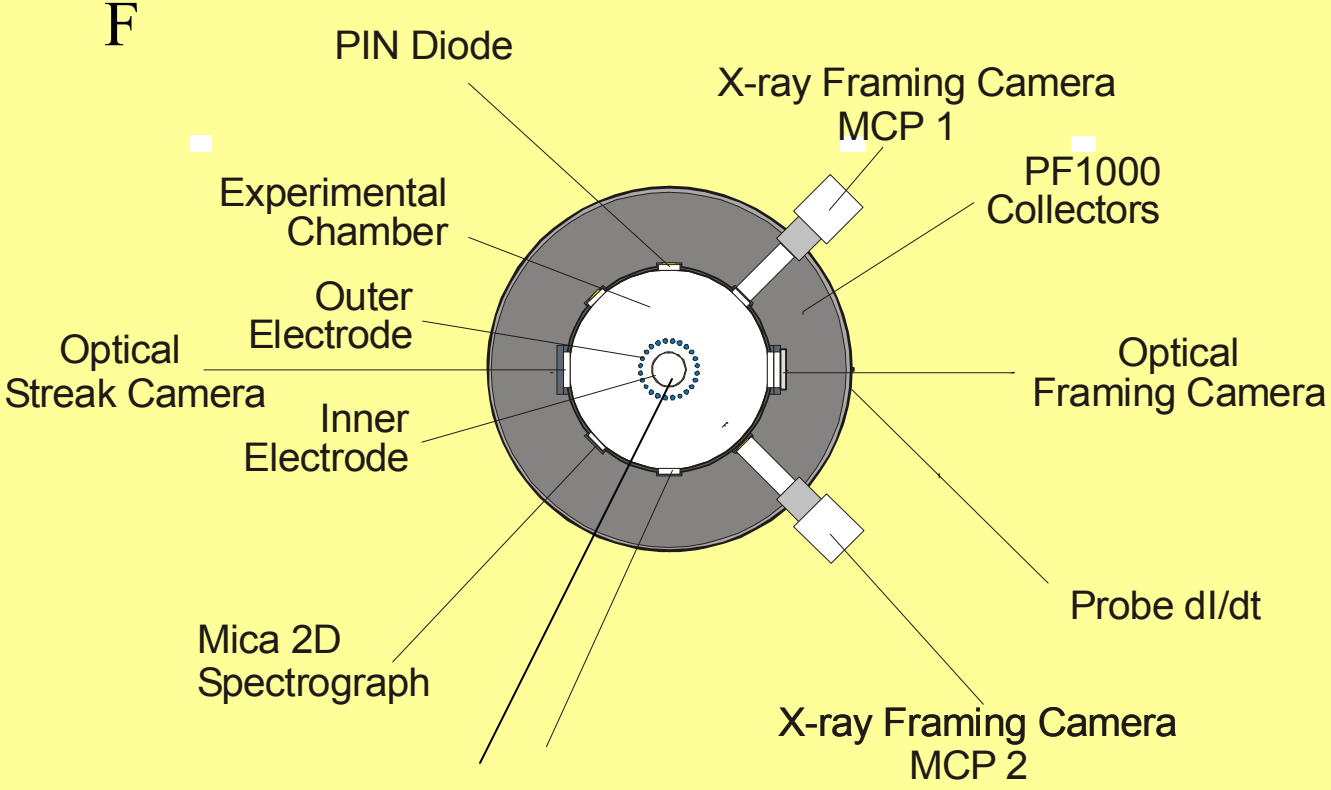
- active diagnostics of the plasma at the axis of the pinch
- dense and cold plasma inside the fiber corona slowing down energy transformations and instability development
- effective sources of intense K-shell of x-rays
- influence on the neutron yield

PF-1000 IPPLM Warsaw

- 1.5-2 MA, 5-10 μs, electrodes l = 60 cm, Φ = 30,40 cm
- load - current sheath (H, D) + Al, CD_2 fiber 100 μm

P
F

PF-1000 scheme of diagnostics



2 **Cherenkov detectors**

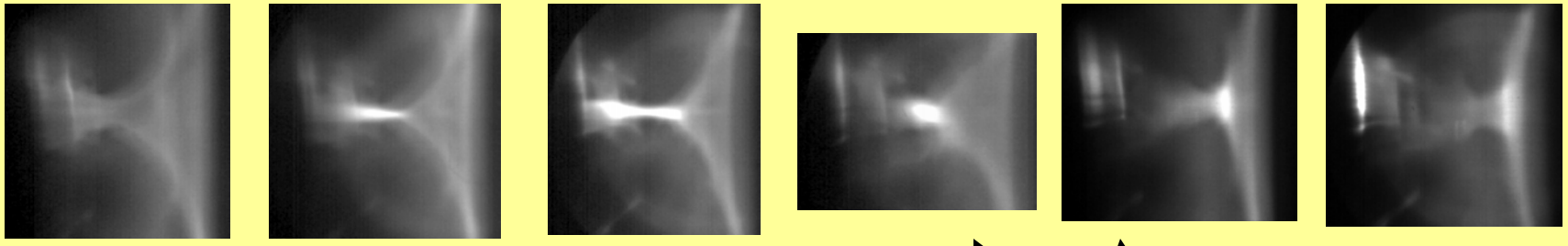
hard x-rays and neutron scintillators
downstream 7 m
upstream 7 m, 41 m
side-on 7 m

3 **silver activated counters**

PF-1000, D current sheath, correlation of neutrons with X-rays [5]

visible frames

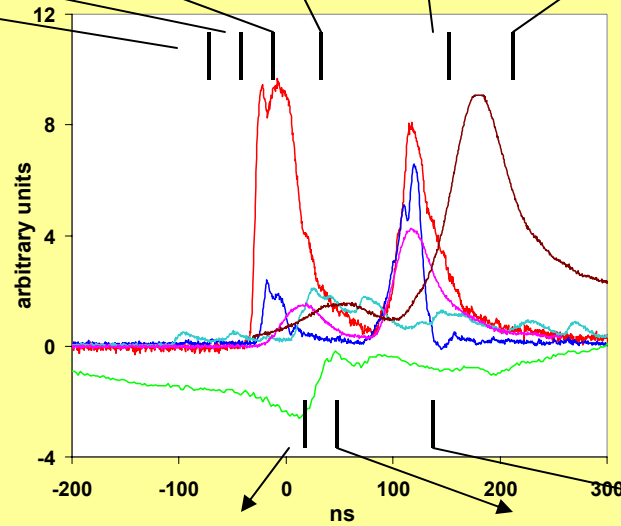
shots No. 4197 and 4165



-40 ns -20 ns 0 ns 40 ns 140 ns 220 ns

1000 kA D current

- neutron yield 10^{10}-10^{11}
- $W_{upstrem}$ ~ 2.7 MeV (2.8 MeV)
- decrease of –z electros & increase of neutrons
- time delay of maximum of neutrons and x-rays - 40-60 ns
- correlation of neutrons with dense, cold and magnetized plasma



soft x

hard x

electron beams -z

electron beams r

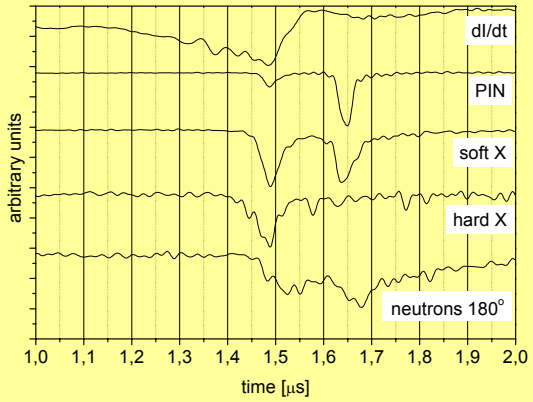
neutrons

dI/dt

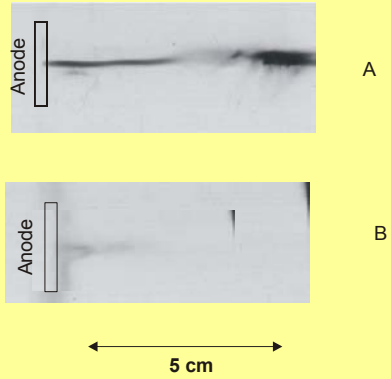
0 ns 40 ns 130 ns

XUV frames

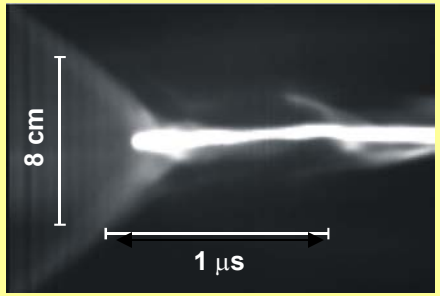
PF-1000 Al wire Φ 120 μm, D_2 current sheath [2]



oscillograms

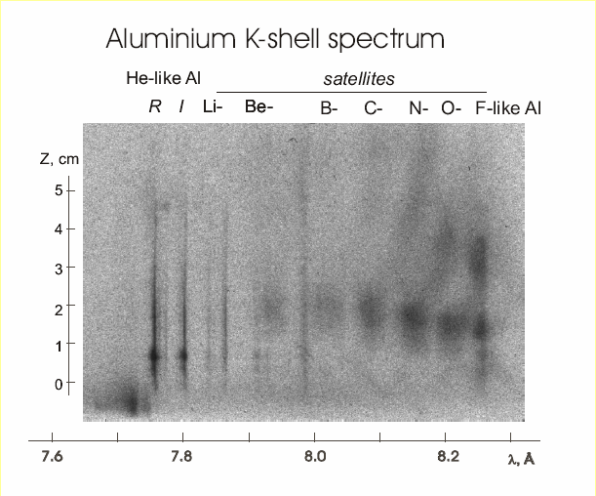


time integrated obscura



visible streak

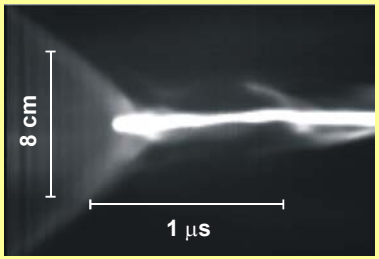
- **forming of long-living wire corona**
- **pulse of keV x-rays from the corona surface**
- **Al K-shell lines T_e~150 eV, n_e~10^{26} m^{-3}**
- **neutron yield 10^{10}-10^{11}**
- **wire has not** important **influence on neutron production**
- **maximum of neutrons ~ 50 ns after hard x-rays**



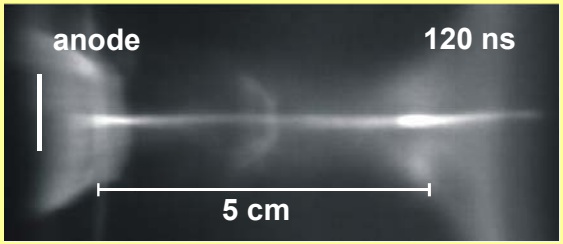
Al K-shell lines

PF-1000, 2 MA

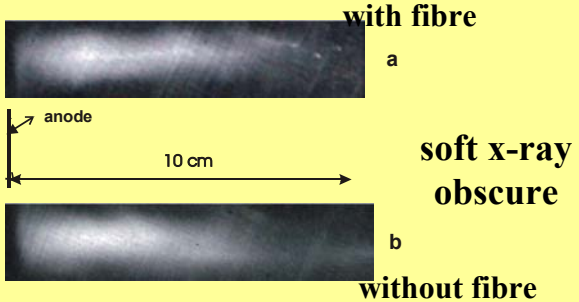
$(CD_2)_n$ fibre Φ 100 μm, 7 cm length, D current-sheath 400 Pa [4]

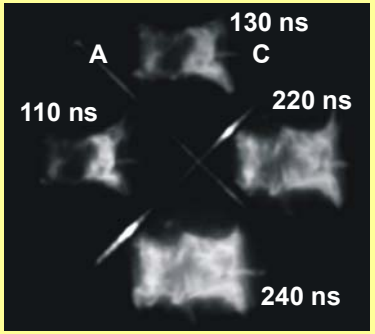


visible streak



visible frame

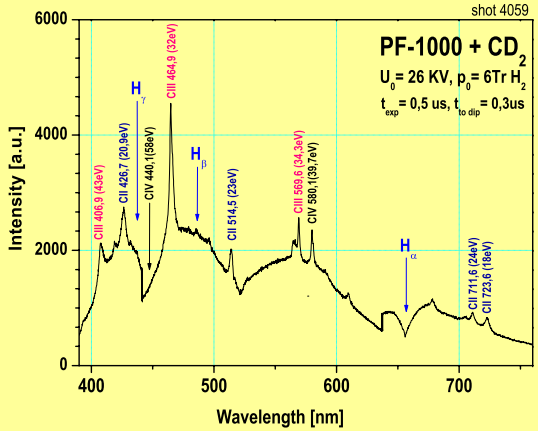




XUV frames

depress of neutron yield (D) 1 order
depress of soft x-rays

*effective cooling of the current-sheath
by the deuterium evaporated from the fiber

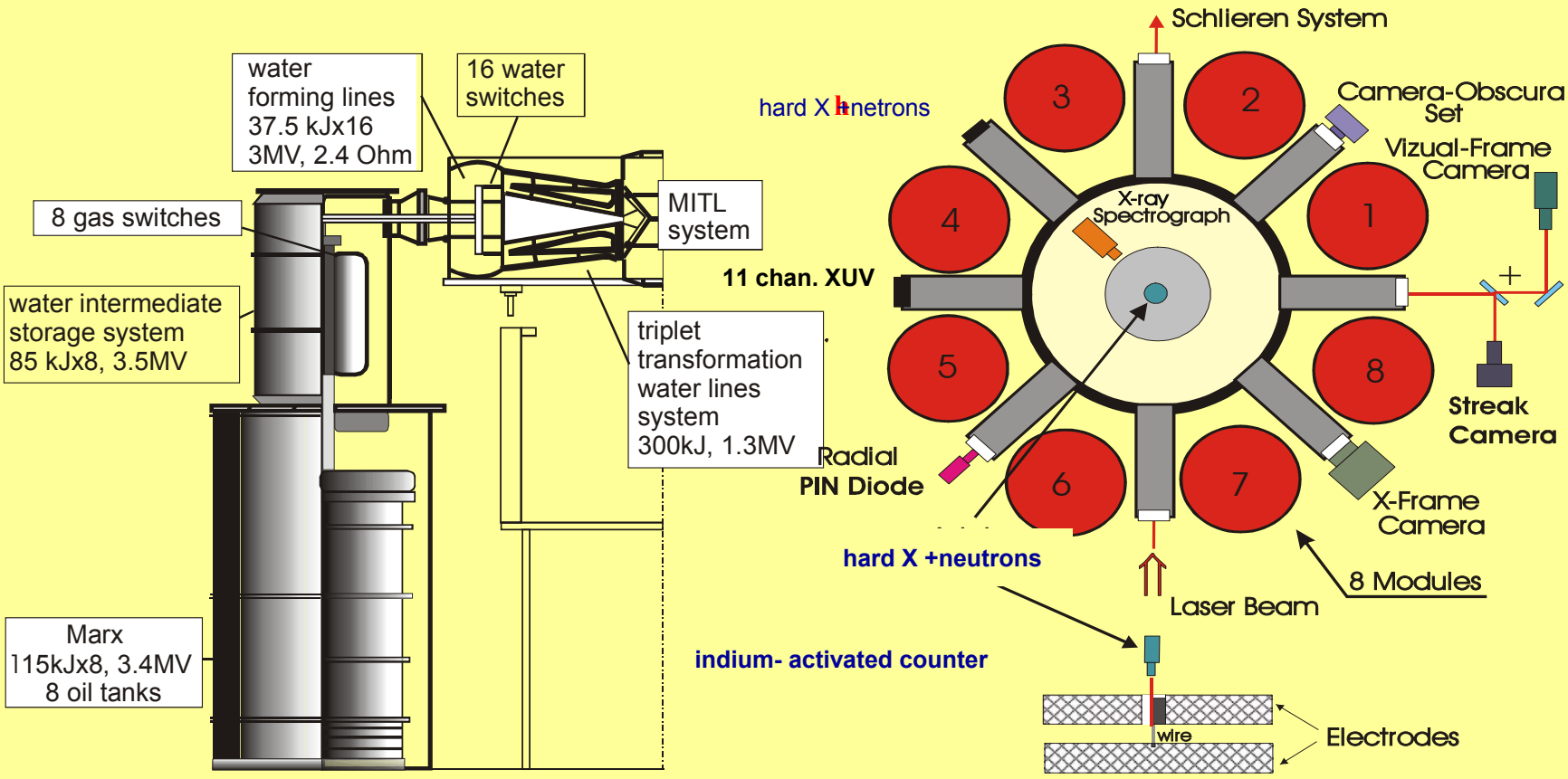


visible spectrum

Russian Research Center, Kurchatow Institute Moscow

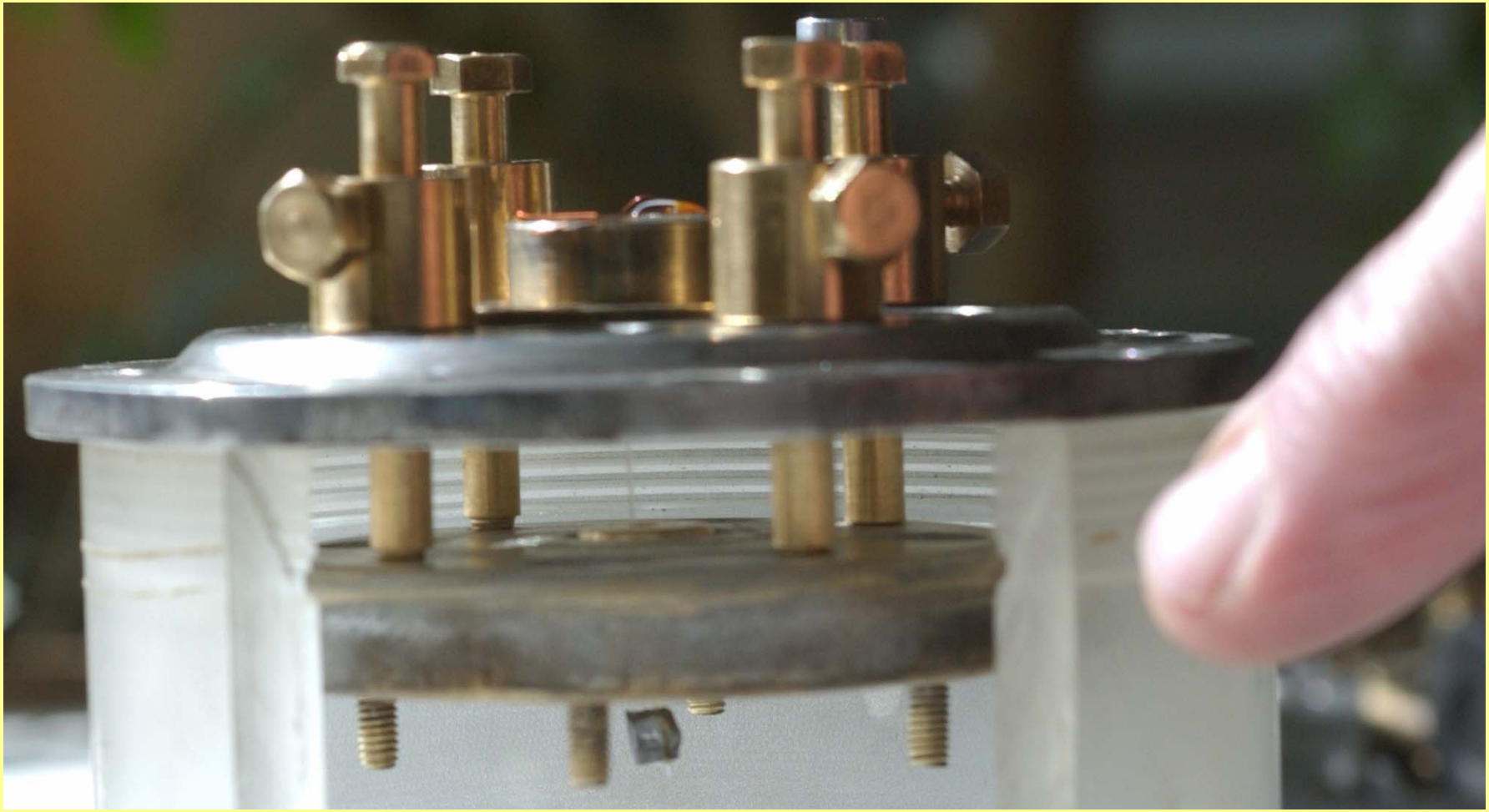
S-300, 8 moduls , 3 MA, 100 ns

S-300 scheme of facility and diagnostics
3 MA, 100 ns

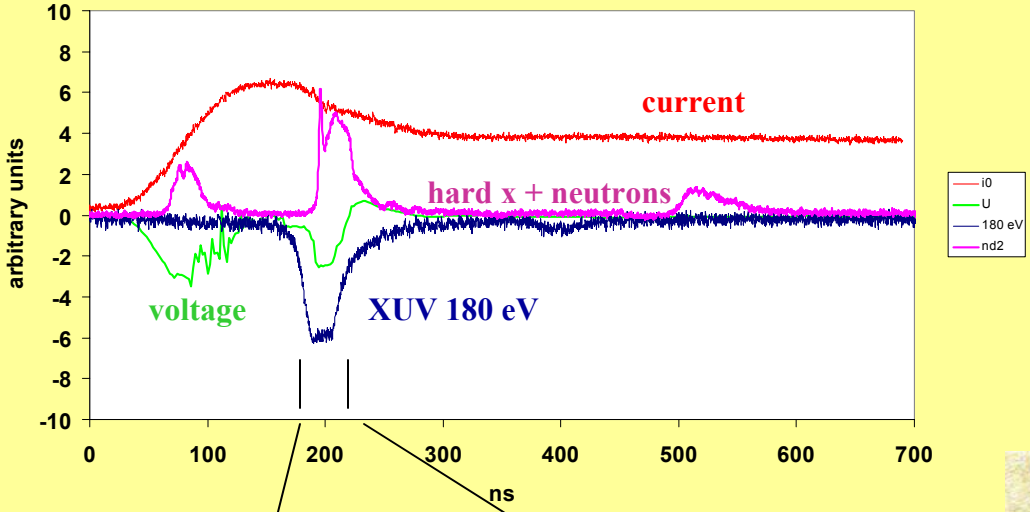


S-300, RRC KI Moscow, 2 MA

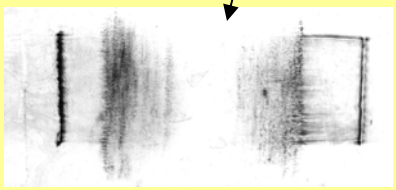
Al, W wire arrays (1x1 cm) + $(CD_2)_n$ fibre Φ 100 μm



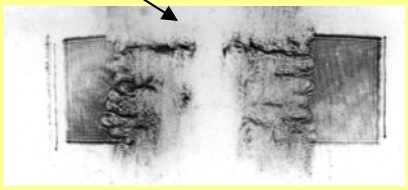
S-300, W wire array (30 wires, Φ 7 μm) + $(CD_2)_n$ fiber Φ 120 μm
neutron yield 10^8



waveforms

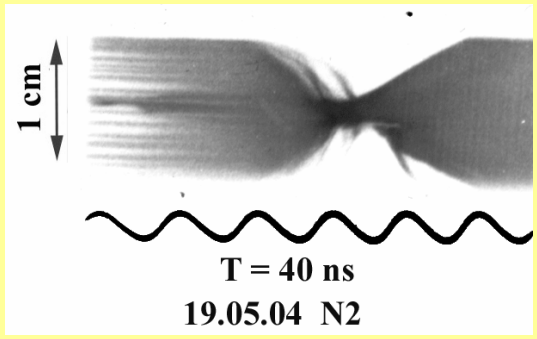


180 ns



220 ns

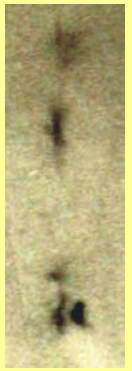
shadows



streak

0

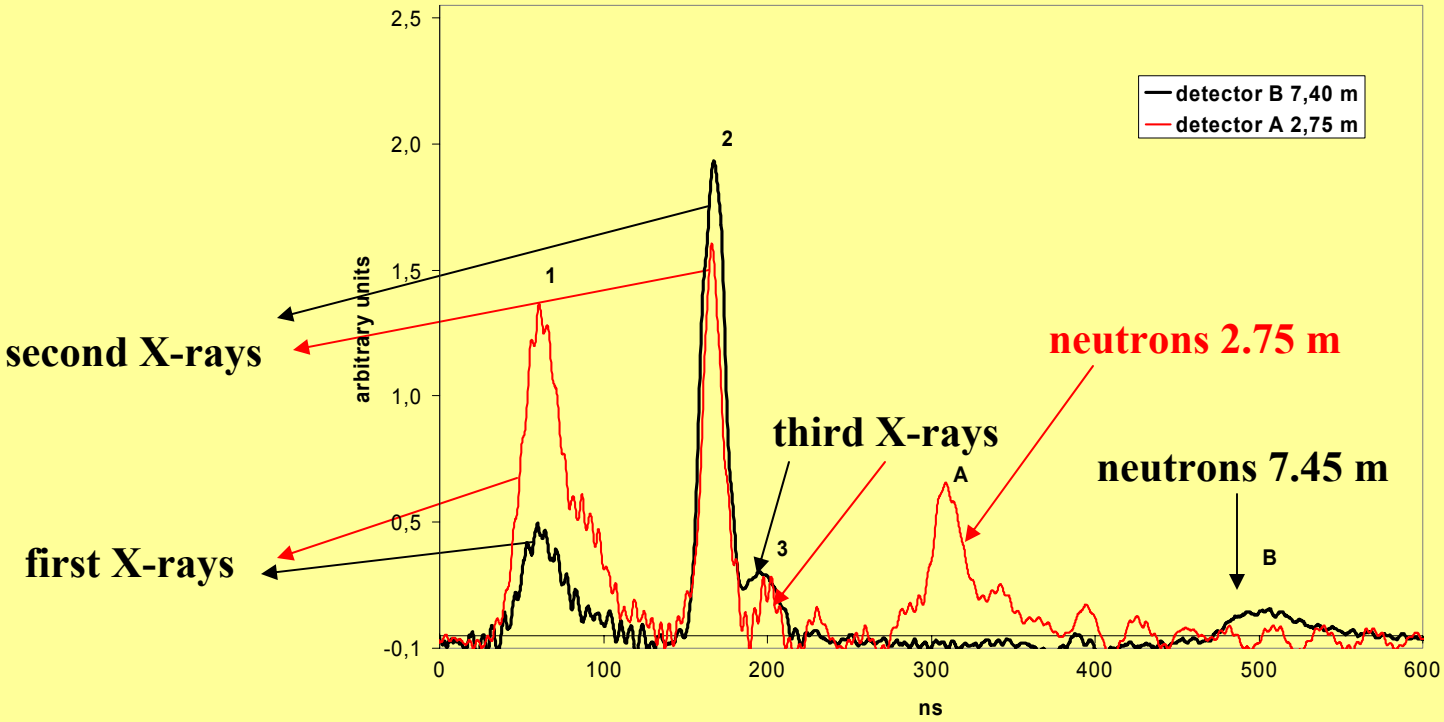
mylar 5 μm



mylar 12 μm

obscure

S-300, Al wire + $(CD_2)_n$ fiber, shot 030530-1
neutron yield 4×10^7



Results: generation of neutrons at implosion of the Al wire onto the CD_2 fiber

S-300, Al, W wire array + $(CD_2)_n$ fiber - results

- neutron yield 10^8
- time delay of maximum of neutrons after hard x-rays 10 ns?
- a few sources of hard x and neutrons
- anisotropy of neutrons – random direction
- hot and cold structures in the pinch
- acceleration of fast deuterons in dense plasma axis locality surrounded by heavy ions
- no evidence of self-generated magnetic B_z field

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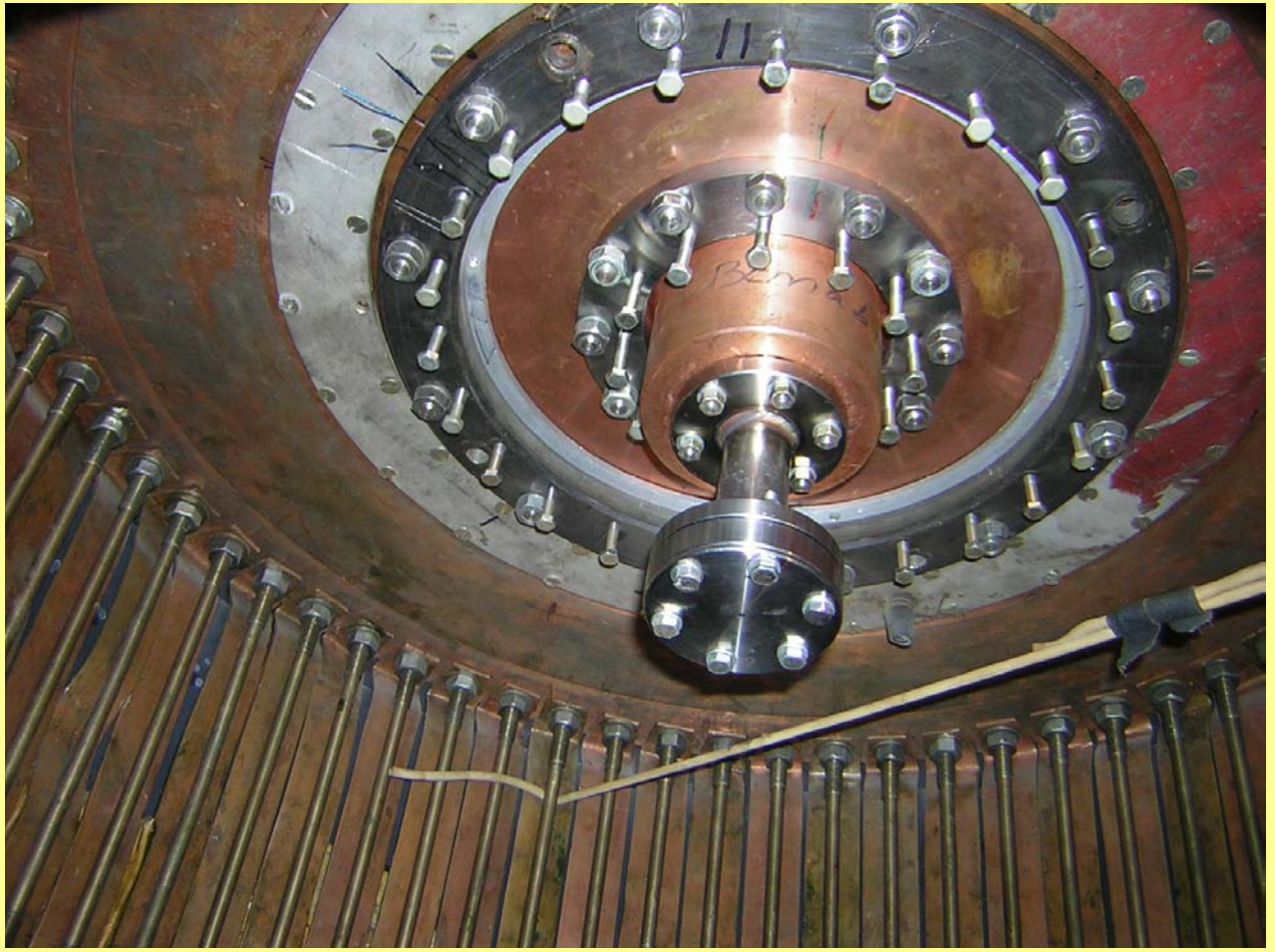
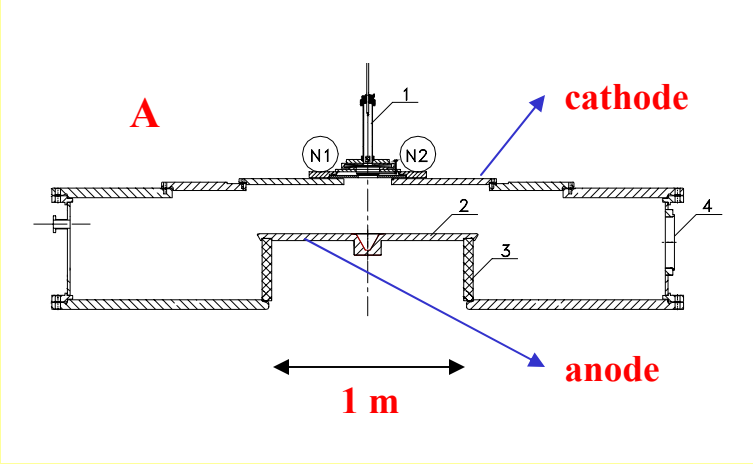
PF-3, 3 MA, 15-20 μs

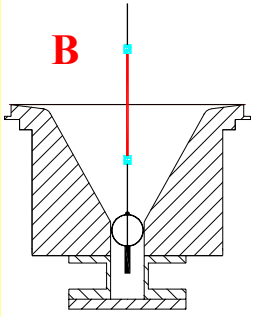


Anode units

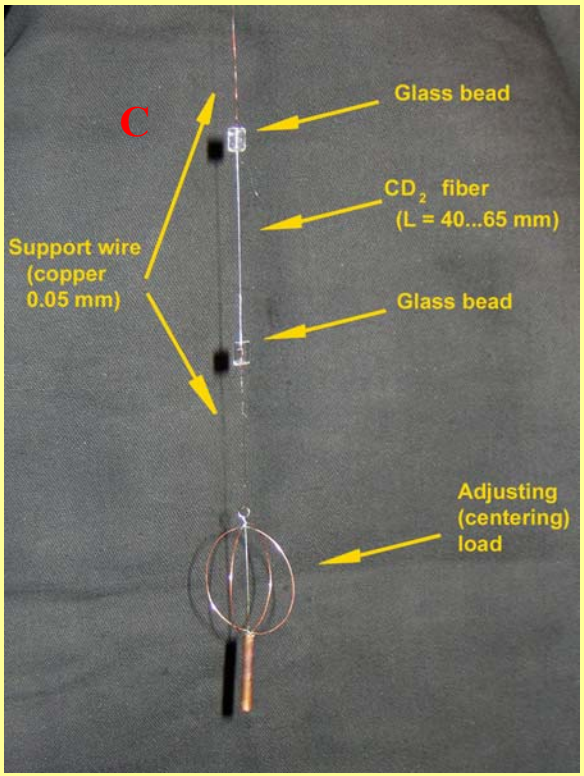
PF-3, 3 MA

$(CD_2)_n$ fibre Φ 100 μm, 7 cm length, Ne, Ar current-sheath 400 Pa





. A: Design of the experimental chamber of PF-3: 1- loading unit, 2 – anode, 3 – insulator, 4 – diagnostic ports, N1 and N2 – activation neutron detectors
B: Design of the anode central part and CD_2 fibre



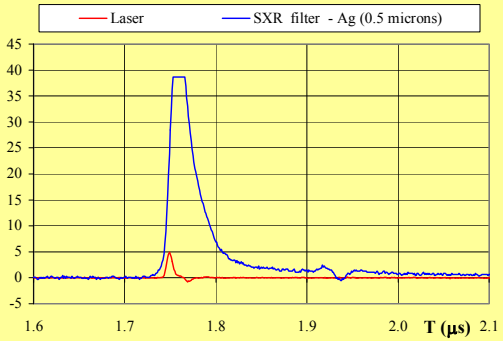
Design of the target with CD_2 fibre

PF-1000, 2 MA

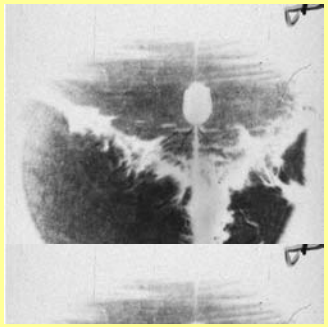
$(CD_2)_n$ fibre Φ 100 μm, 7 cm length, Ne current-sheath 400 Pa

Example of shots without neutron yield

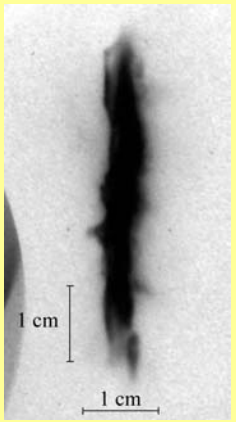
Shot# 18, 3 torr Ne



oscillogram: x-rays, laser

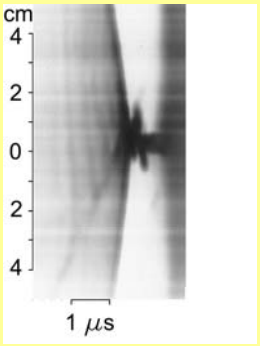


laser record

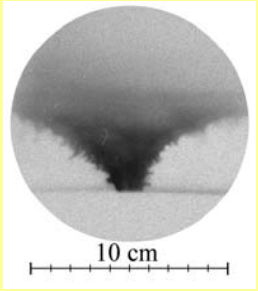


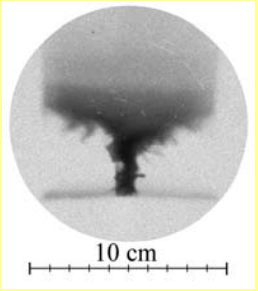
x-ray pinhole record
17 μm Be

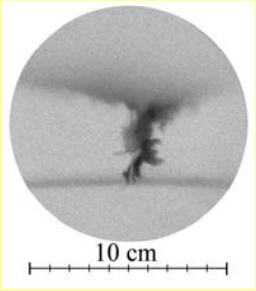
Shot# 22, 3 torr Ne



visible streak



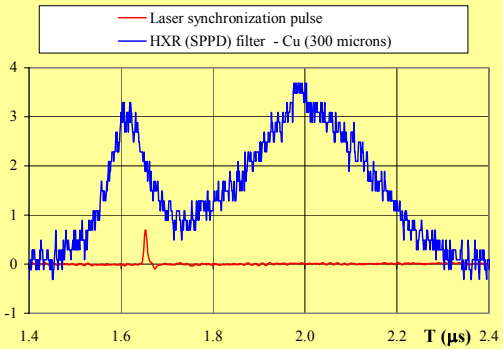




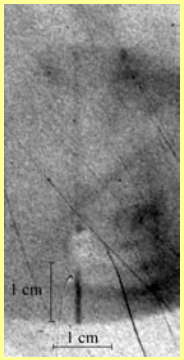
visible frames

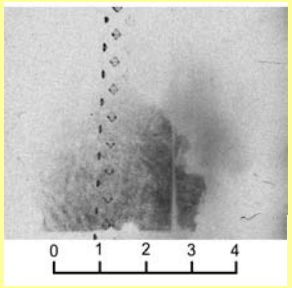
Example of shots with neutron yield

Shot# 50, 3 torr Ar. **Ny = 6.5·10⁶ ±50%**



oscillogram: x-rays, laser

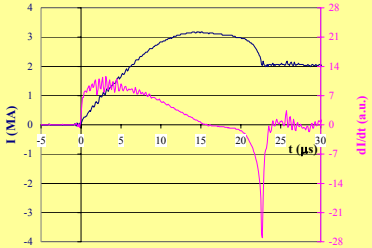




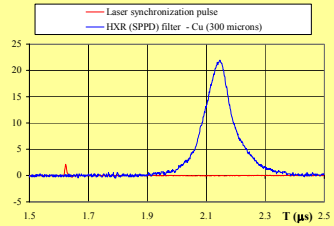
x-ray pinhole record 17 μm Be

laser record

Shot# 26, 3 torr Ar **Ny = 6·10⁶ ±50%**

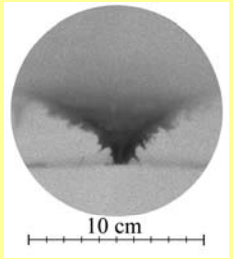


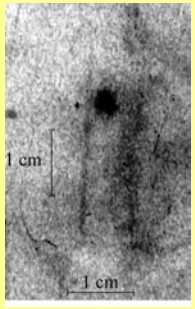
oscillogram: current, current derivative



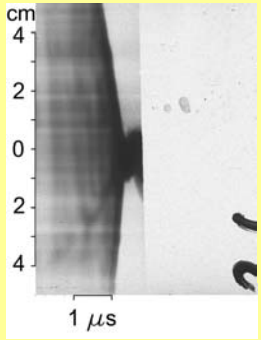
oscillogram: x-rays, laser

laser record





visible frames



visible streak

x-ray pinhole record 17 μm Be

Conclusions

Experimental results

PF –

- time delay between x-rays and neutrons
- production of neutrons at the Al wire in the axis
- depression of neutrons at the CD_2 fiber in the axis
- production of neutrons from CD_2 in Ar current sheath
- acceleration of fast particles in non-axis locality
- correlation of neutrons with dense and cold plasma at instability development
- important role of self-generated B_z field
- beam-target mechanism of neutron production

Z-pinch –

- production of neutrons from the fiber in the axis
- acceleration of fast deuterons in dense plasma axis locality surrounded by plasma of wire array
- time delay of neutrons after x-rays
- presents of cold and hot localities in the pinch
- beam-target mechanism of neutron production

Table of neutron yield at the different devices (D-D)

device	record shot	load	plan
JET	10^{14}	gas 10^{20} m^{-3}	
ITER		gas 10^{20} m^{-3}	10^{16} (2010)
W-7		gas 10^{20} m^{-3}	10^{12} (2010)
Z-device (18 MA)	10^{13}	gas 10^{26} m^{-3}	
Angara 5 (3 MA)	10^{12}	gas 10^{25} m^{-3}	
PF-1000 (1.5 MA)	2.10^{11}	gas 10^{24} m^{-3}	
S-300 (1.5 MA)	10^{8}	solid $(CD_2)_n$ 10^{25} m^{-3}	
OMEGA	2.10^{11}	cryogenic	
PALS		solid $(CD_2)_n$	? (2005)
Compas		gas 10^{20} m^{-3}	?

Thank you for attention