Polycapillaries for diagnostics in magnetic fusion plasmas ?

D. Pacella EFDA-Garching, Germany
(ENEA-Frascati, Italy)

Collaboration ENEA-INFN-CEA

ENEA- Frascati: D. Pacella, L. Gabellieri, A. Romano
& technical pool of FUS-MAG

INFN- Frascati: S: Dabagov, F. Murtas, D. Hampai

CEA- Cadarache: D. Mazon

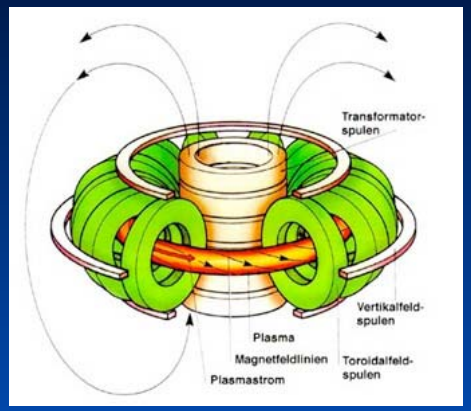
Channeling 2010, Ferrara 6/10/2010

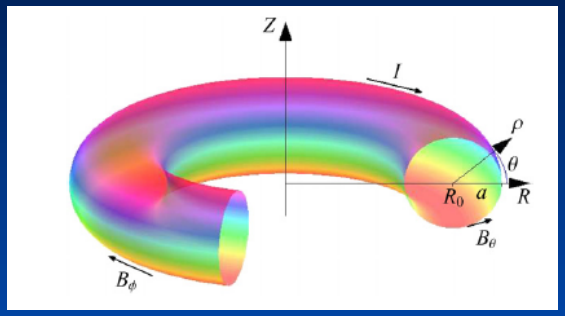
Why X-ray polycapillary optics could be useful
in magnetic fusion plasmas ?

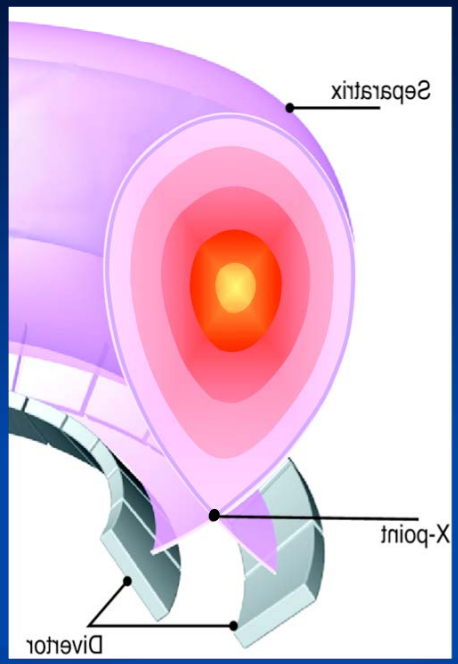
Preliminary results for using polycapillaries
as imaging optics for extended sources (plasmas)

Possible schemes to be used in soft X-ray
diagnostics for magnetic fusion plasmas

What is a magnetic fusion plasma ?







Extended (~ 1 ÷ 50 m^3)

Hot

Central temperature ~ 1 ÷ 20 KeV

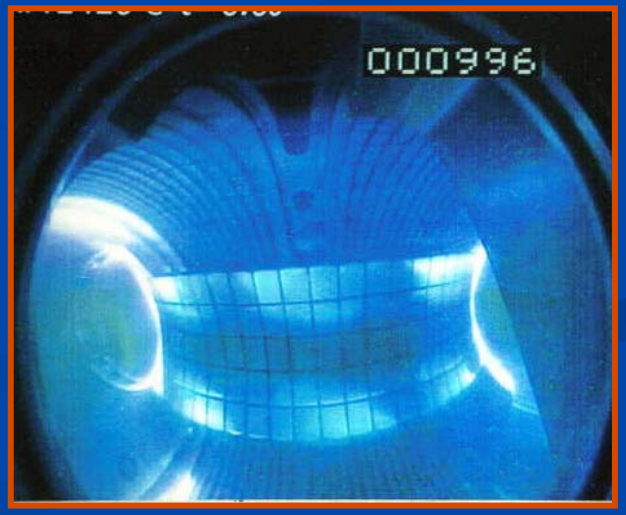
Edge temperature ~ 10 ÷ 50 eV

Low density

central density ~ 10^{20} particles/m^3

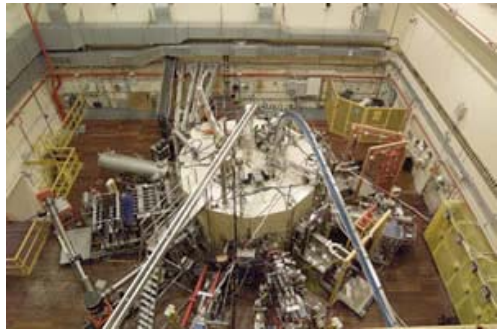
edge density ~ 10^{18} particles/m^3

High power density (~ MW/m^3)



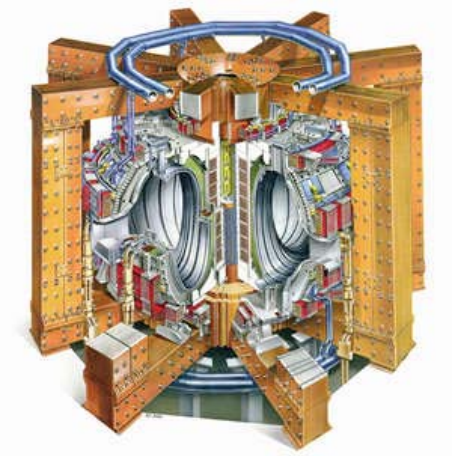
Experiments (Tokamak)

"Domestic" experiment (FTU)



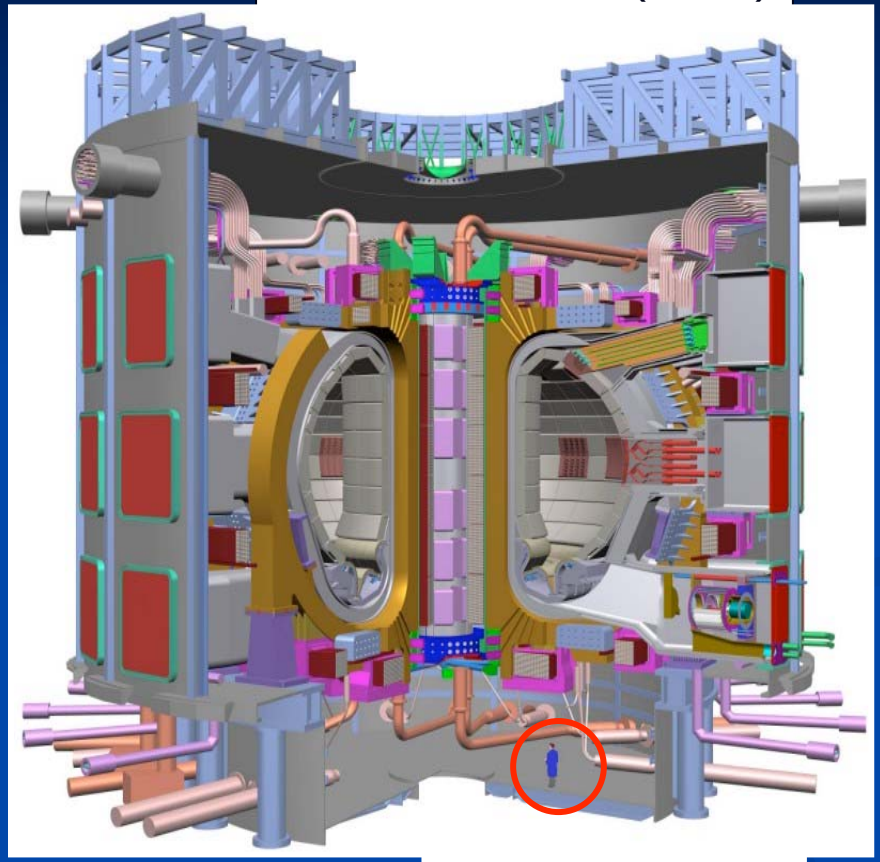
1.65 m^3
a= 0.3 m
R=0.93 m

"Continental" (european) tokamak (JET)



50 m^3
a=0.96 m
R=2.89 m

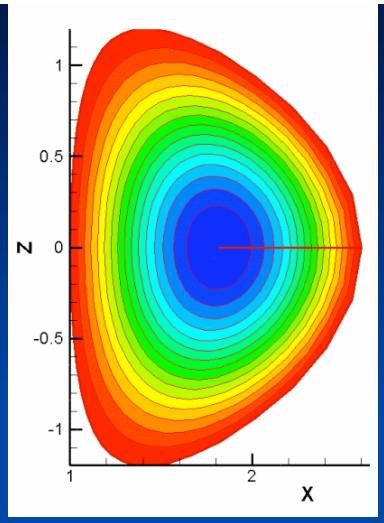
"world" tokamak (ITER)



490 m^3
a=2 m
R=6.2 m
P fus = 500 MW

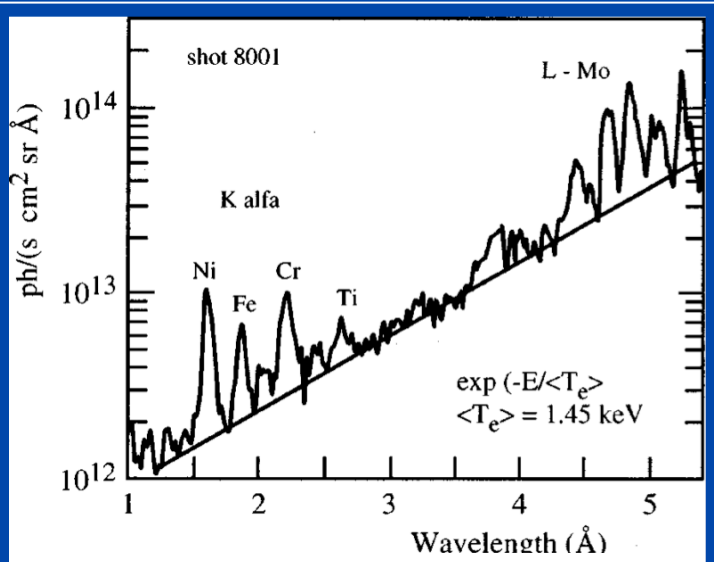
Relevancy of soft X-ray emissions

Surfaces of SXR isoemissivity
Poloidal cross section



$$B_i = \int_{l_i}\int_{E}\sum_{z}[W^z_{ff}+W^z_{fb}+W^z_{bb}]\Omega_D\varepsilon_D(E)dEdl$$

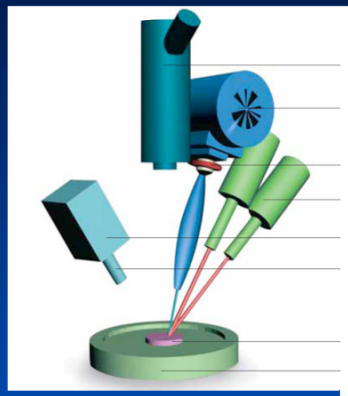
SXR emissivity W ~ 10^{16} ÷ 10^{18} ph/(s m^3 sr) [1-20 keV]



SXR spectra are very rich of crucial information

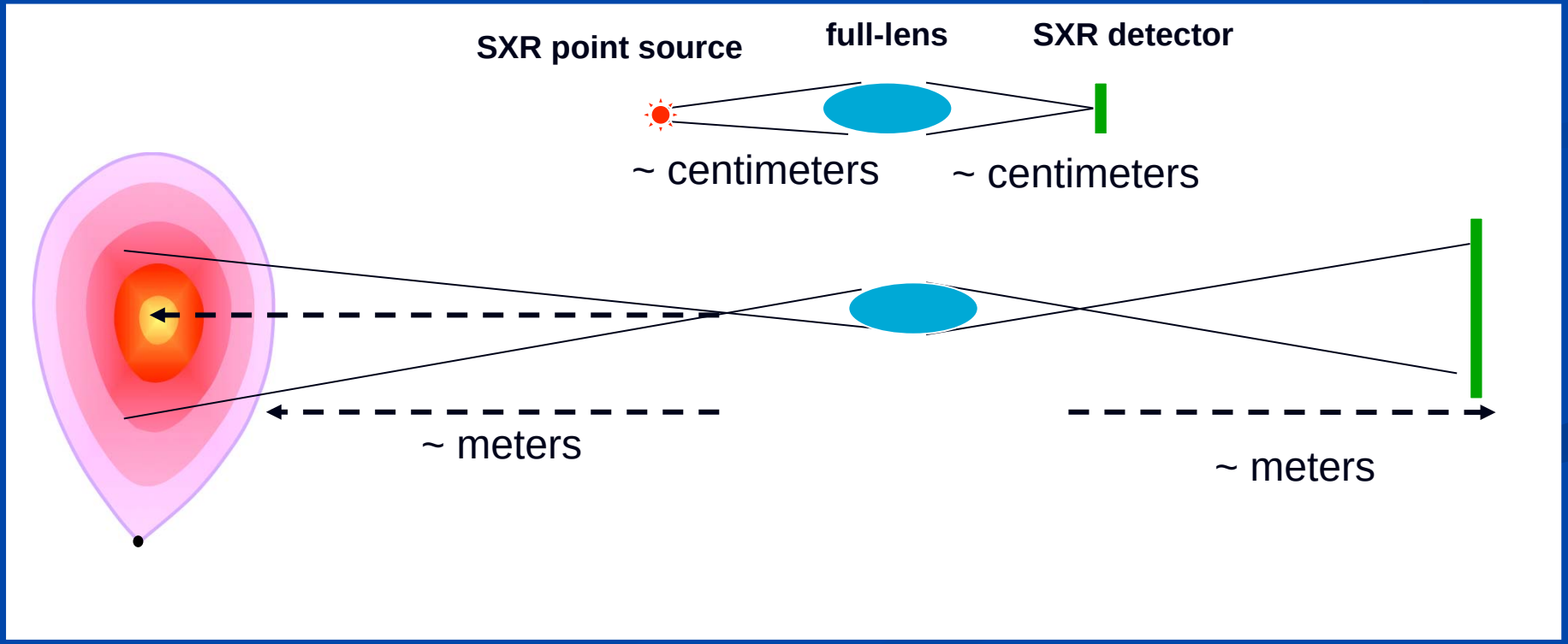
- **Plasma emits broadband: microwaves, IR, visible, VUV, SXR, Hard-X, gamma, neutrons. Particles**
- **SXR emissions carry a lot of information over the entire plasma, allowing fast (ms to microsecond) monitoring in 3D of fluid and kinetics processes, and impurity content as well.**
- **SXR diagnostics in MCF does not require high spatial resolution**

Polycapillary optics for magnetic fusion plasmas



Until now polycapillary lens mainly are used in microscopy or microfluorescence with:

- Small sources (mm)
- Short distances (cm)



Preliminary tests with polycapillaries (September 2010) **(Laboratory LNF-INFN)**

Setup for radiography of the mask (sample)

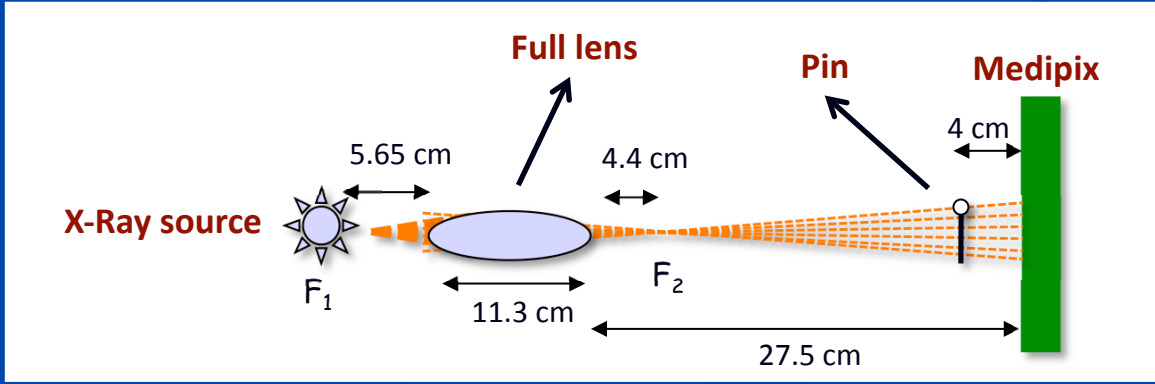
Medipix 256 X 256 pixels

Pixels 55 μm X 55 μm

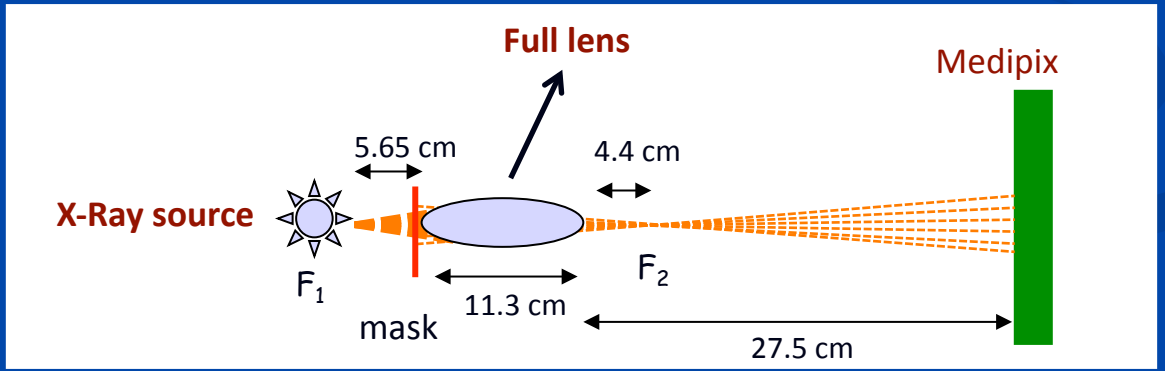
area 1.5 cm X 1.5 cm

Silicon semiconductor

Medipix2 developed by the Medipix2 collaboration at CERN [] X. Llopart et al., /IEEE Trans. //Nucl. Sci./, Vol. 49 (5) (2002) 2279]

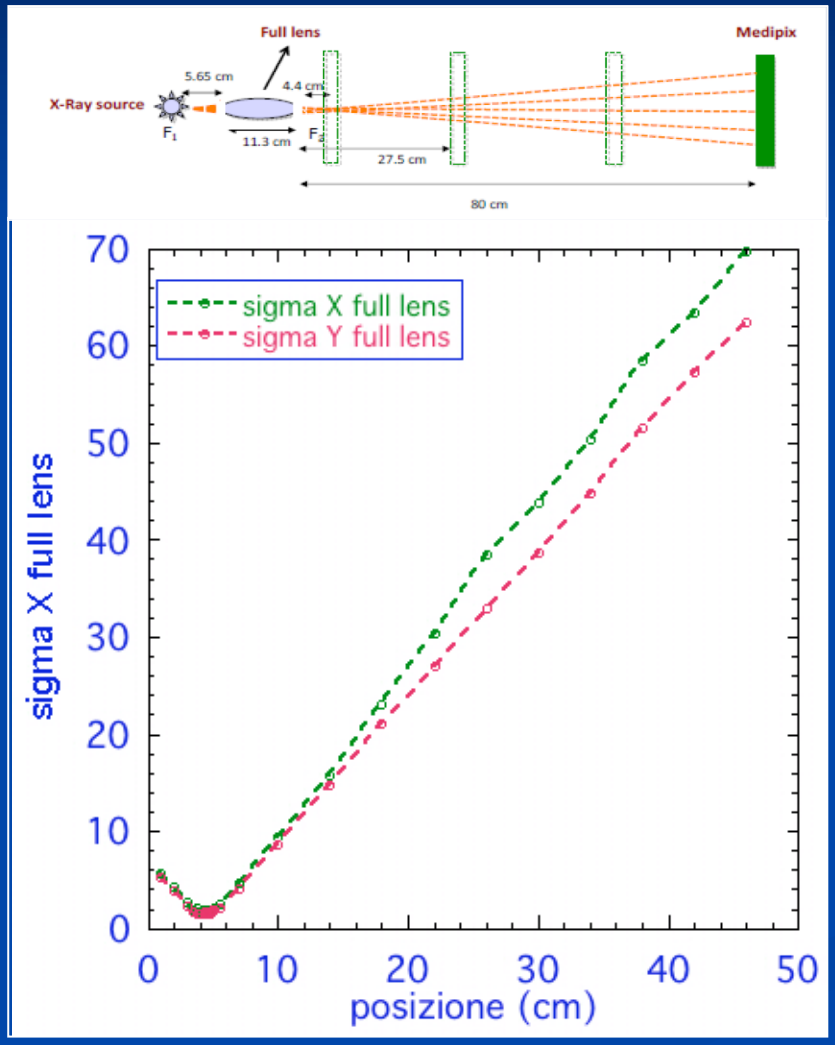


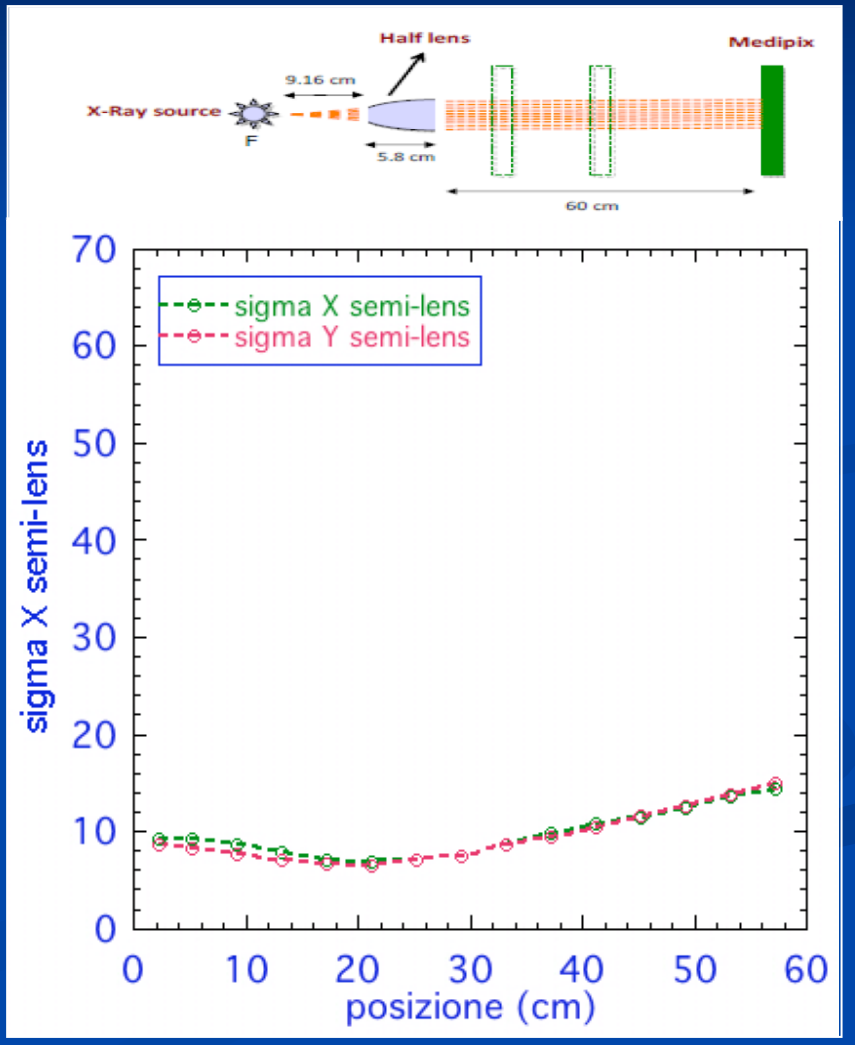
Setup for imaging of a mask



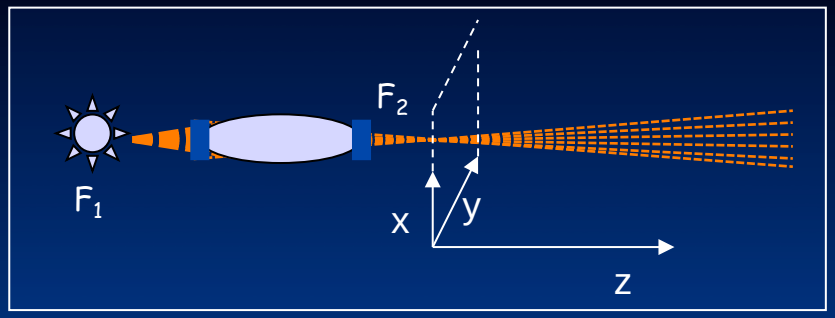
Divergence full-lens and half-lens

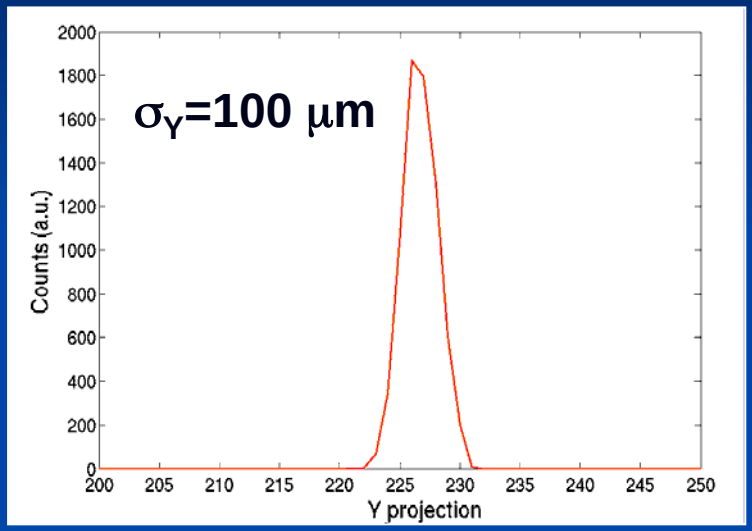
Len	Length	$Sect_{input}$	$Sect_{output}$	F_{input}	F_{output}
Full-lens	11.3 cm	4 mm	4 mm	5.65 cm	4.4 cm
Semi-lens	5.8 cm	4 mm	6 mm	9.16 cm	

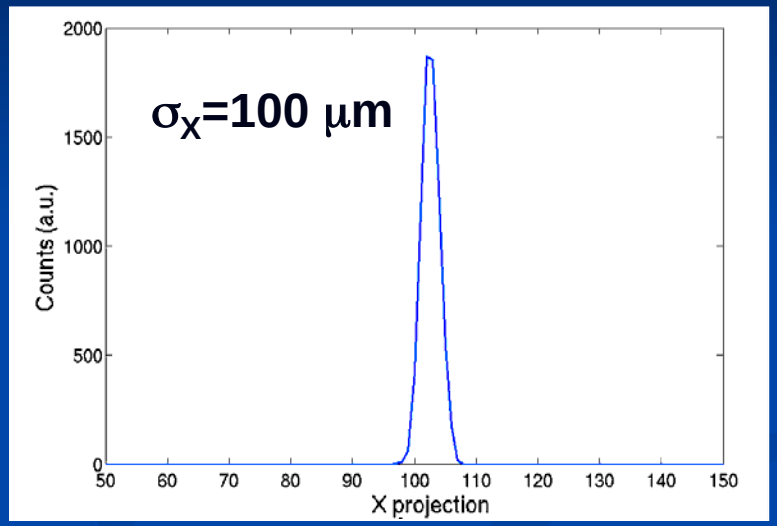




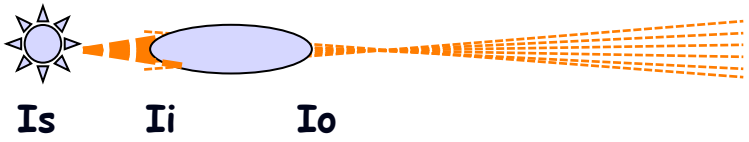
Focal spot







Transmission (full lens)



T=Io / Ii ~ 6 %

Imaging of a pin (500 μm)
X-ray tube (Mo anode) at 25 kV

Radiography of the pin

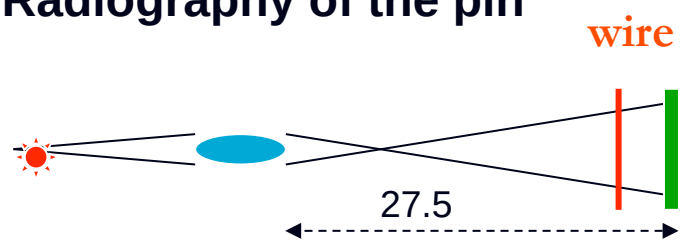
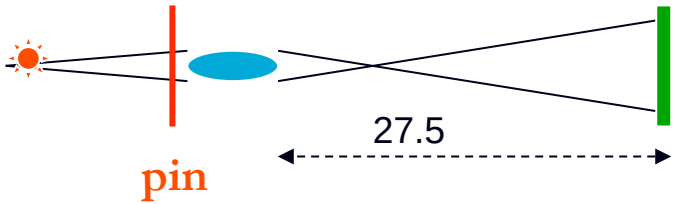
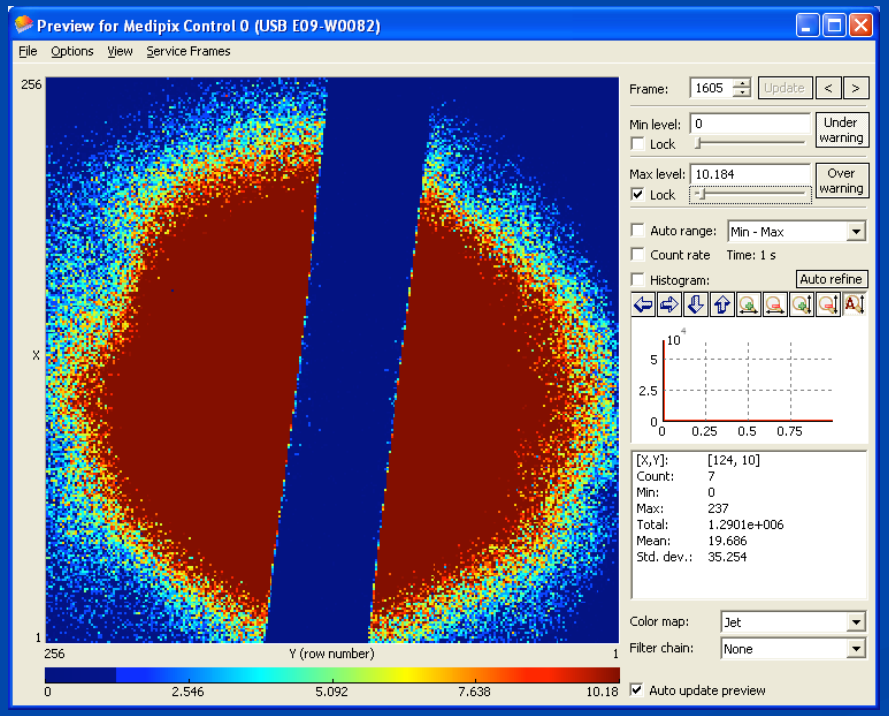
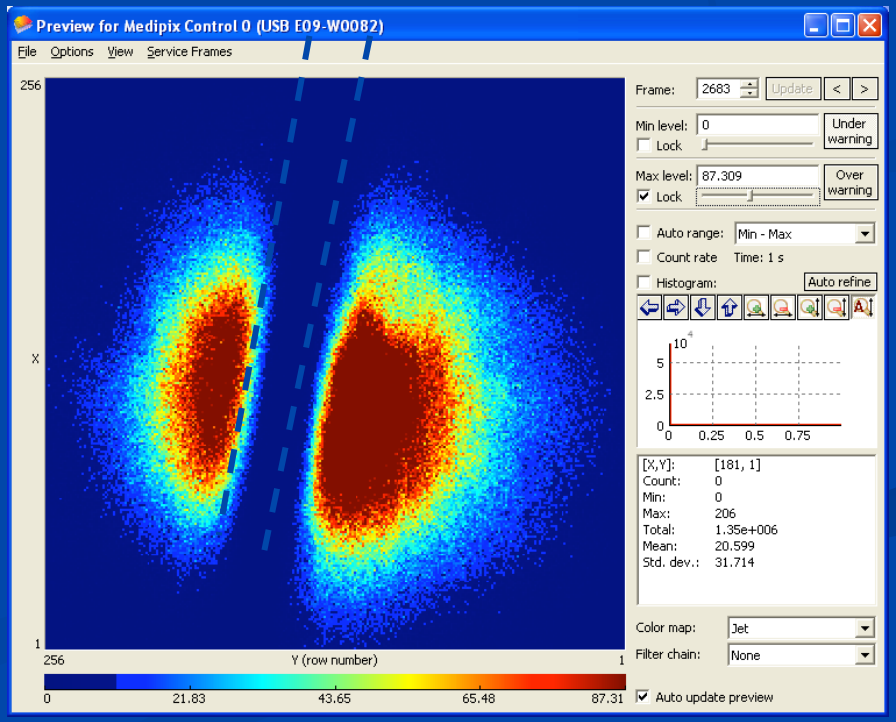


Image of the pin with full lens







Imaging of a Needle

Radiography of the needle

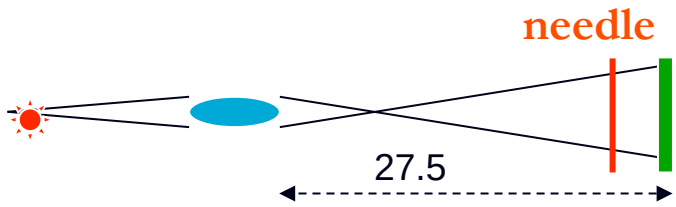
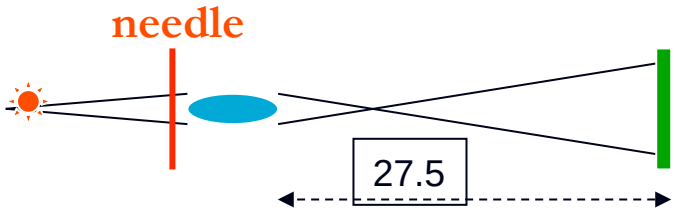
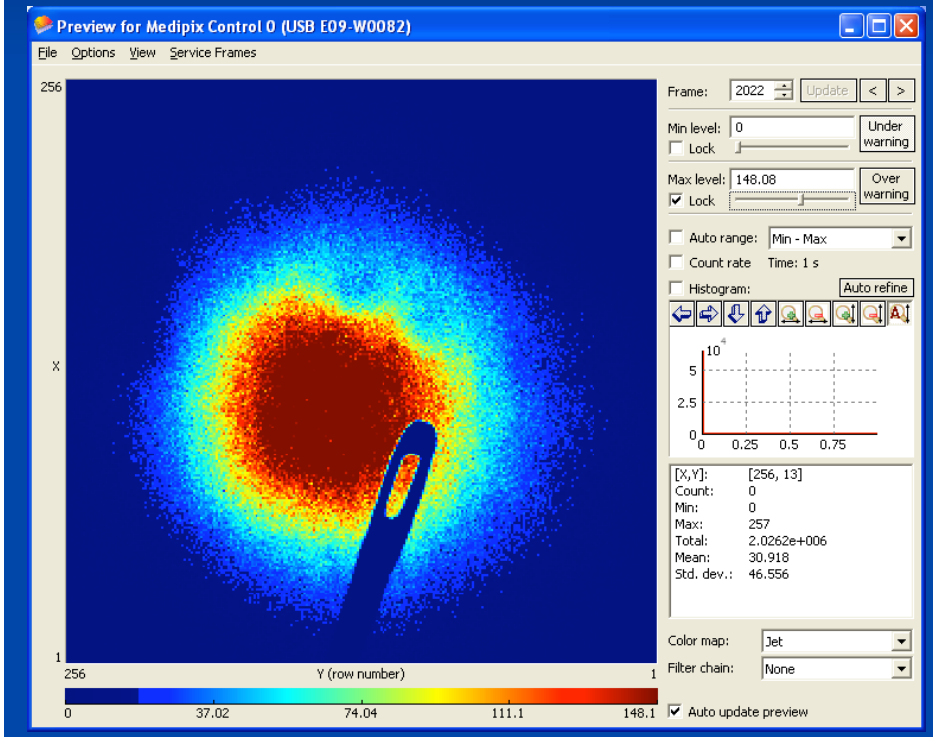
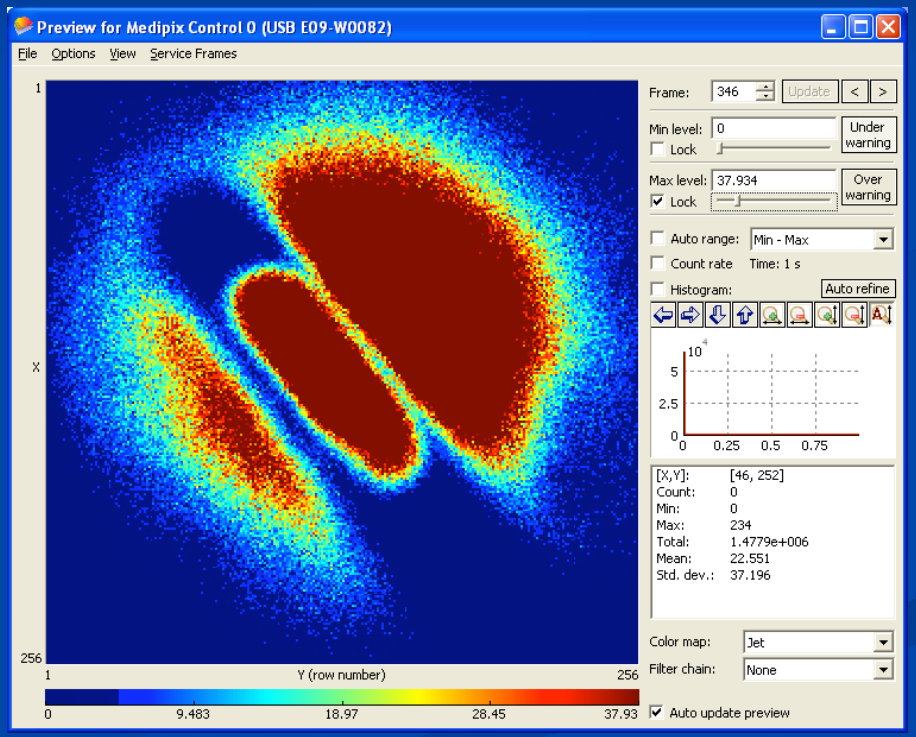


Image (magnified) with full lens

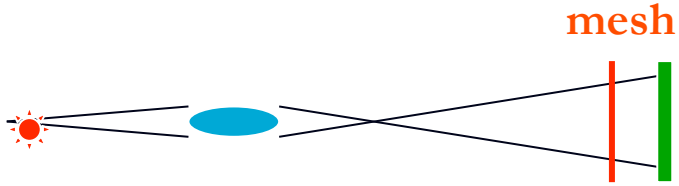






Mesh with holes 400 μm

Radiography of the mesh



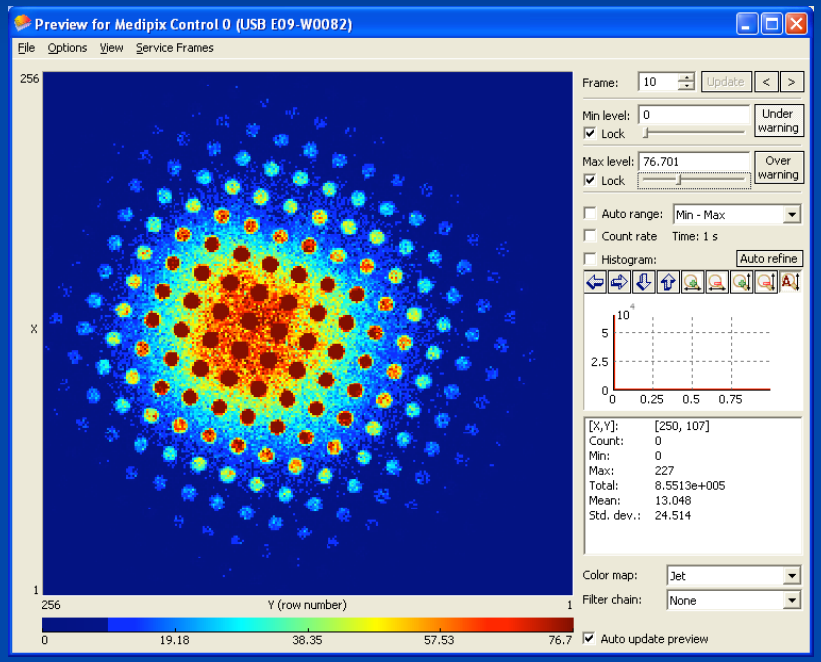
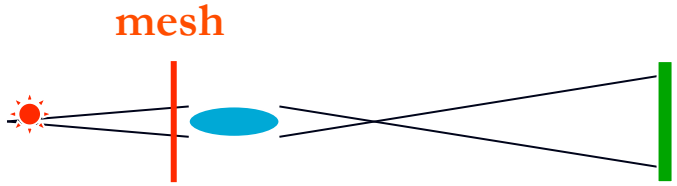
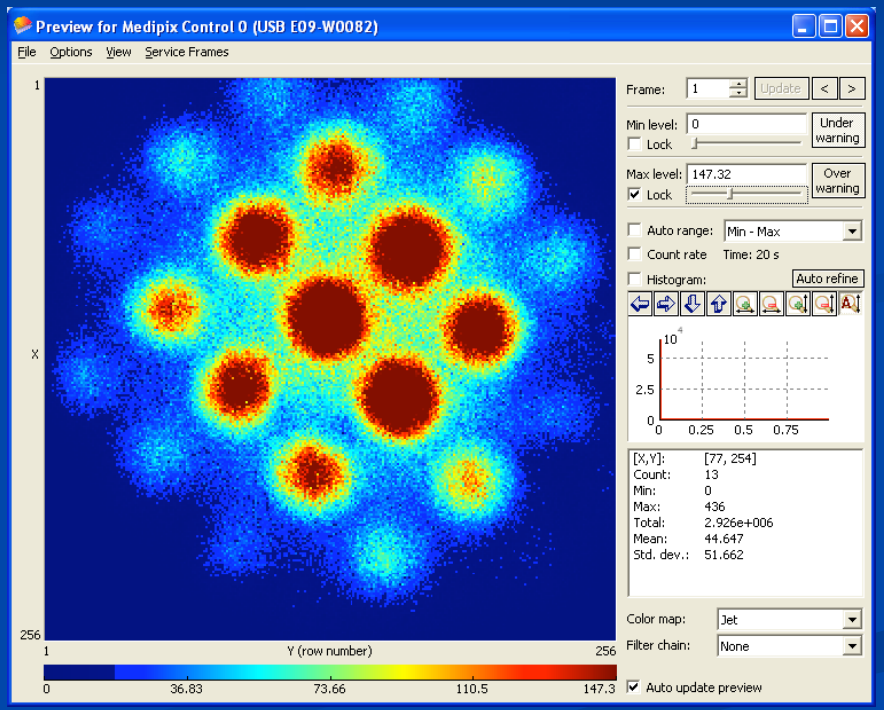


Image of the mesh with full lens



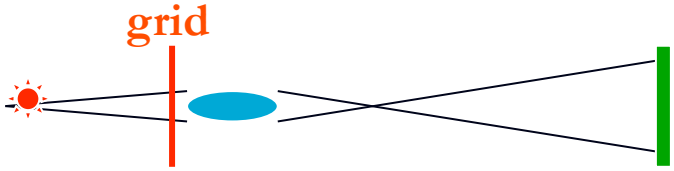


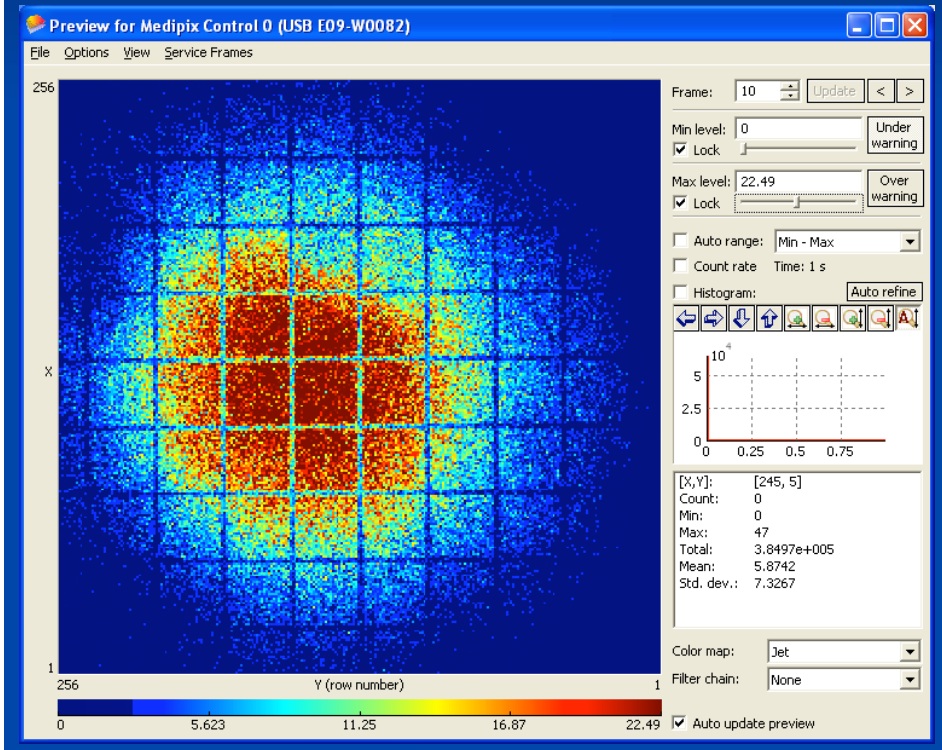
Magnification 6 X

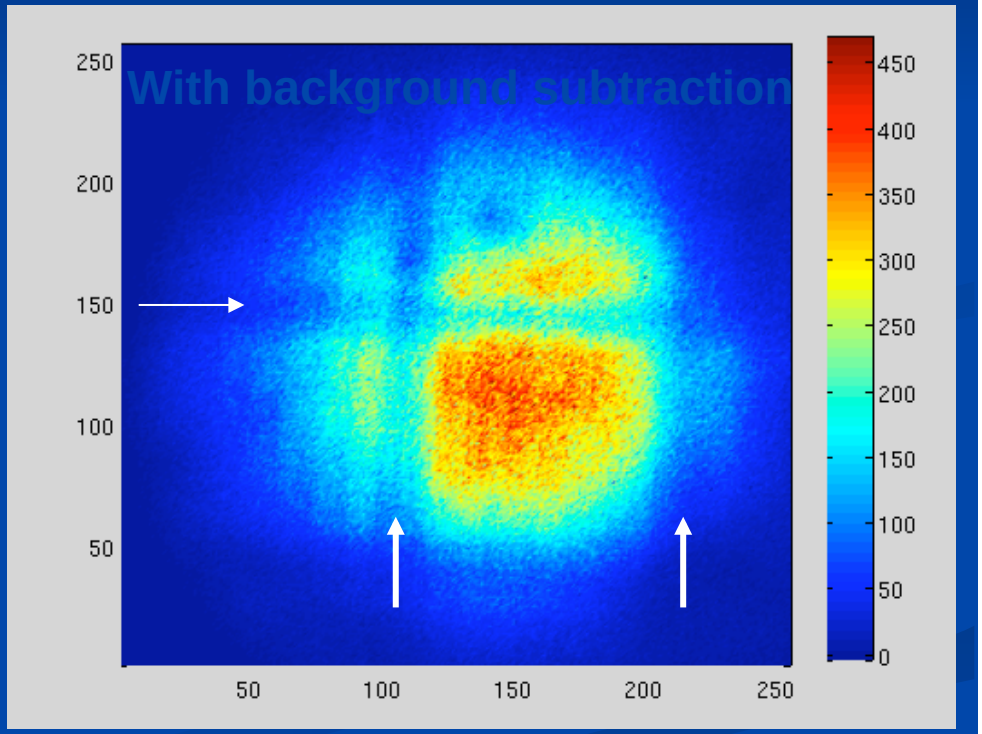
Rectangular grid with wires 100 μm pitch 1.3 mm

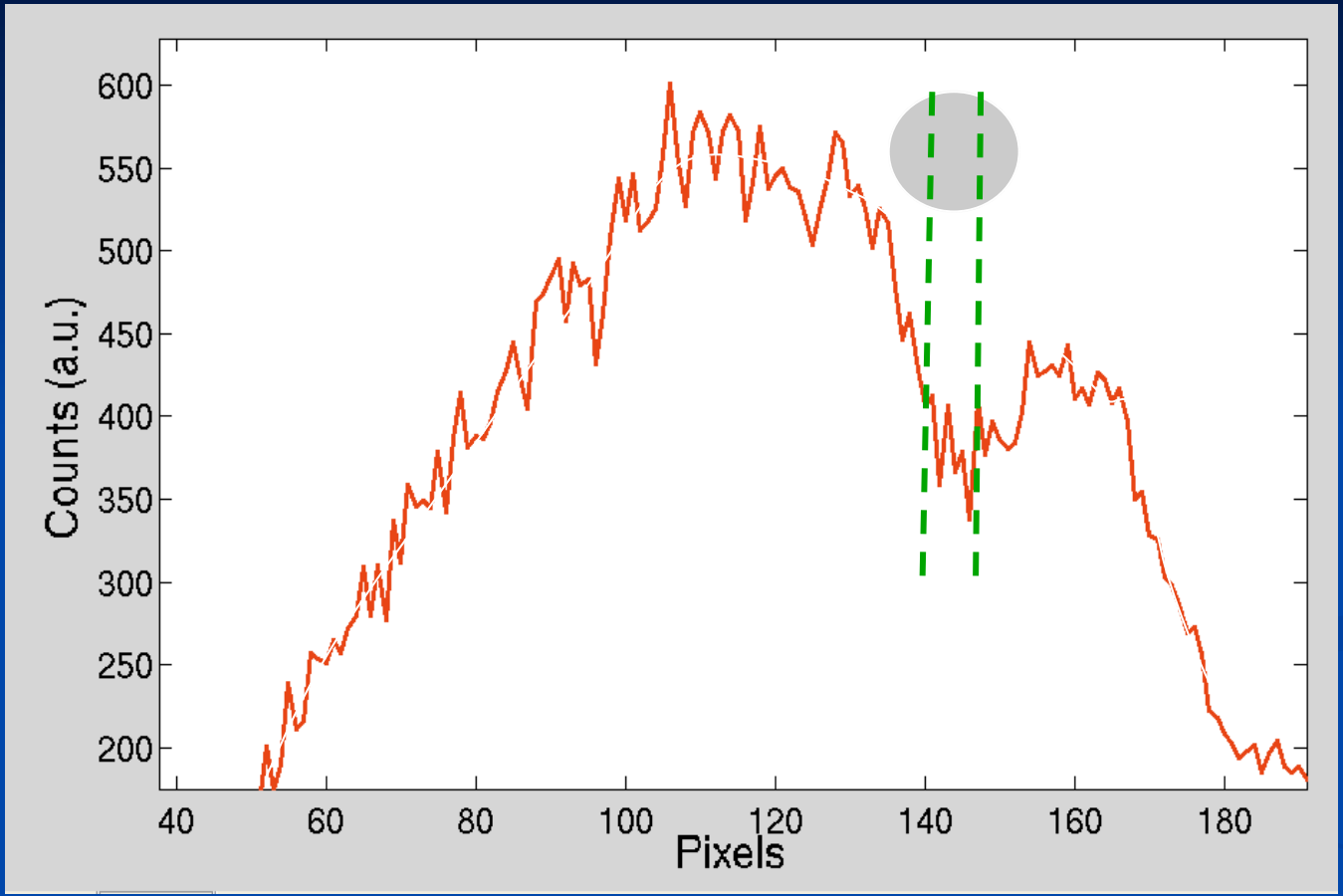
Radiography of the grid

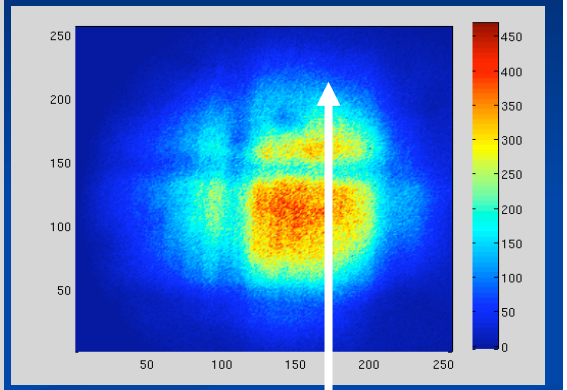
Image of the grid with full lens





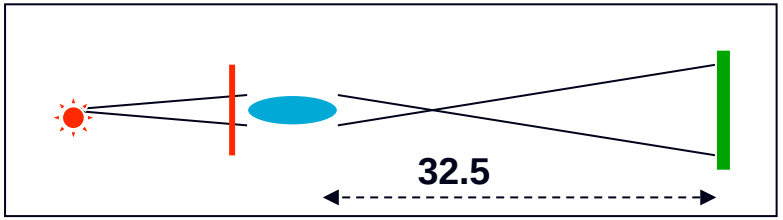


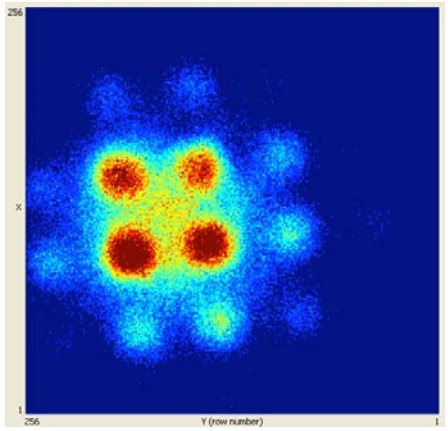


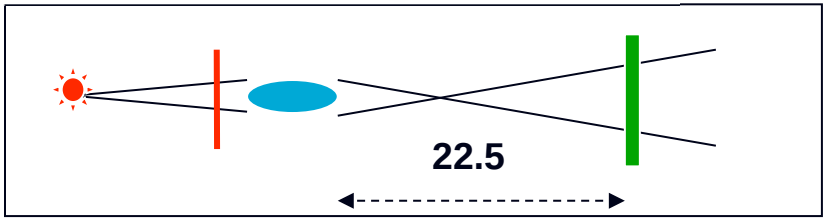


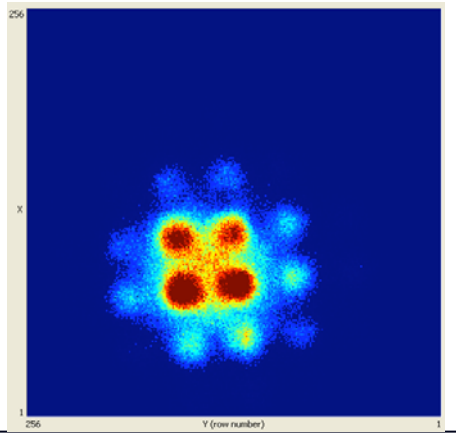
Resolving Power (d/Δx) ~ 4mm / 40μm = 100 where d is the diameter of the lens

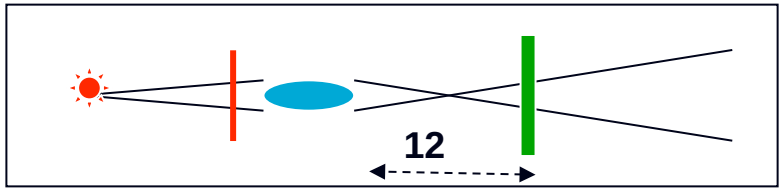
Images of the mesh with holes, at different magnifications

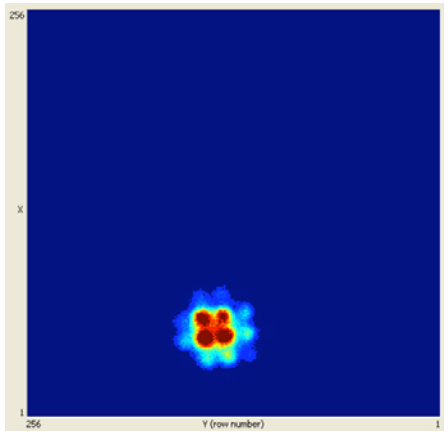


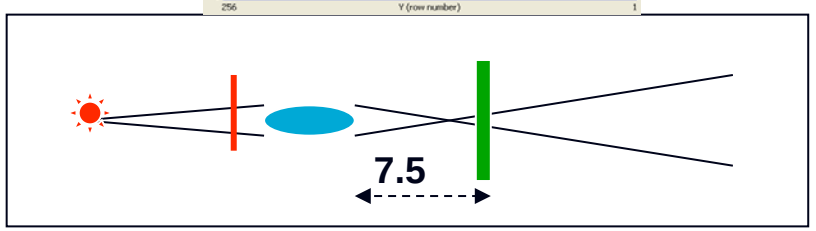


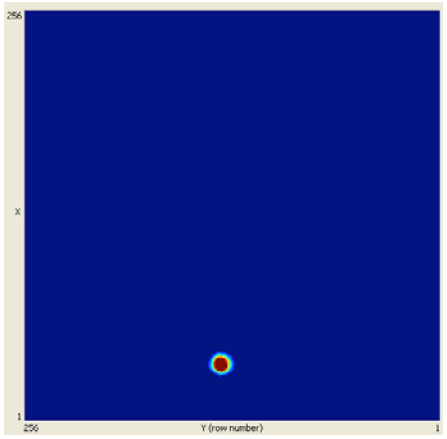






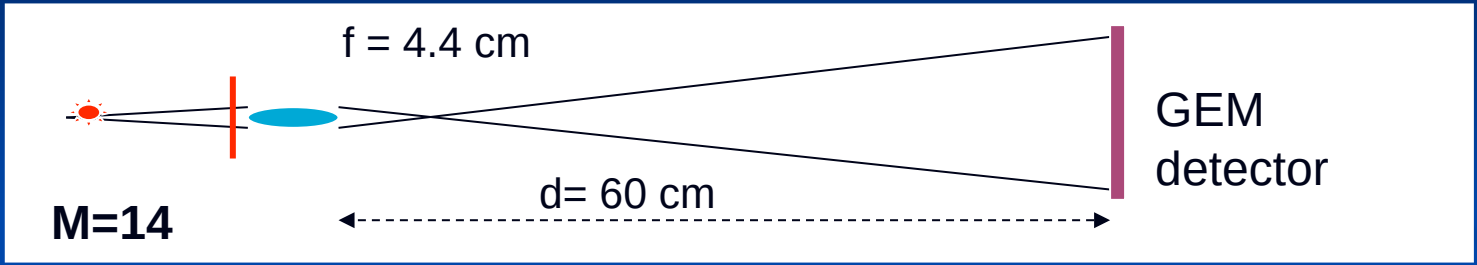






Imaging with a detector (GEM) of large area at large distance

Images with Gem Pixels Detector with a linear array of 128 pixels 500 um X 500 um
Images are obtained with a scan in direction perpendicular to the array



Spot (no mesh)

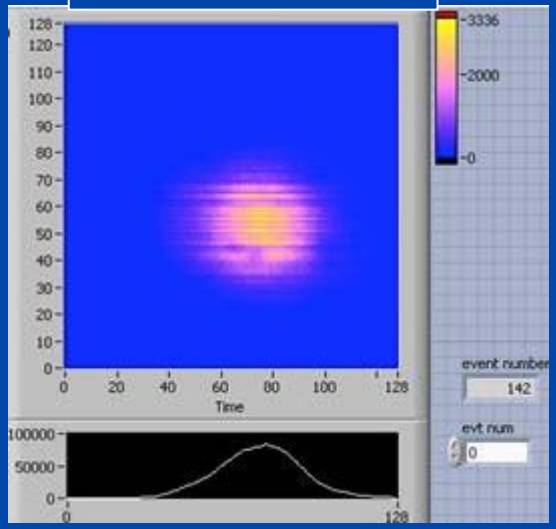
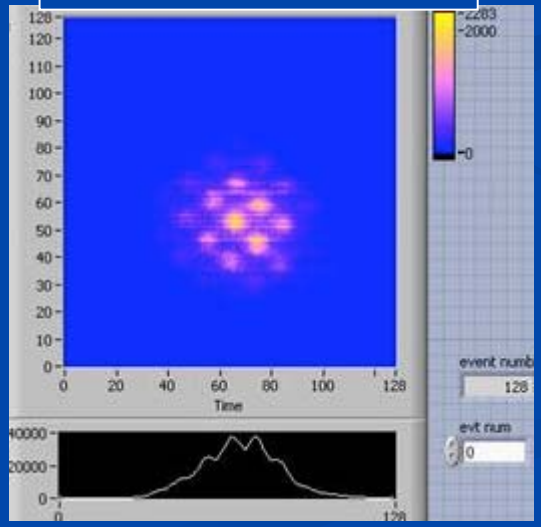


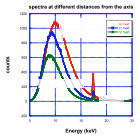
Image of the mesh

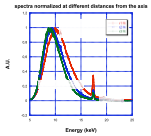


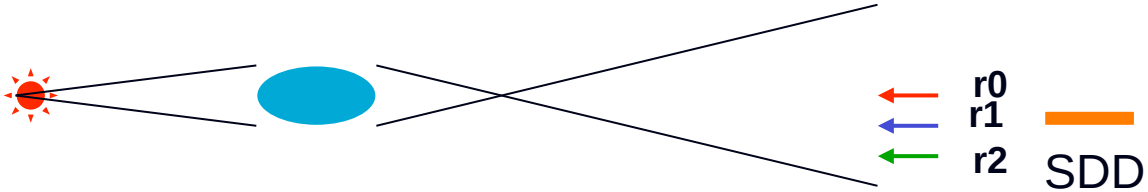
Imaging at large distance (d >> f)

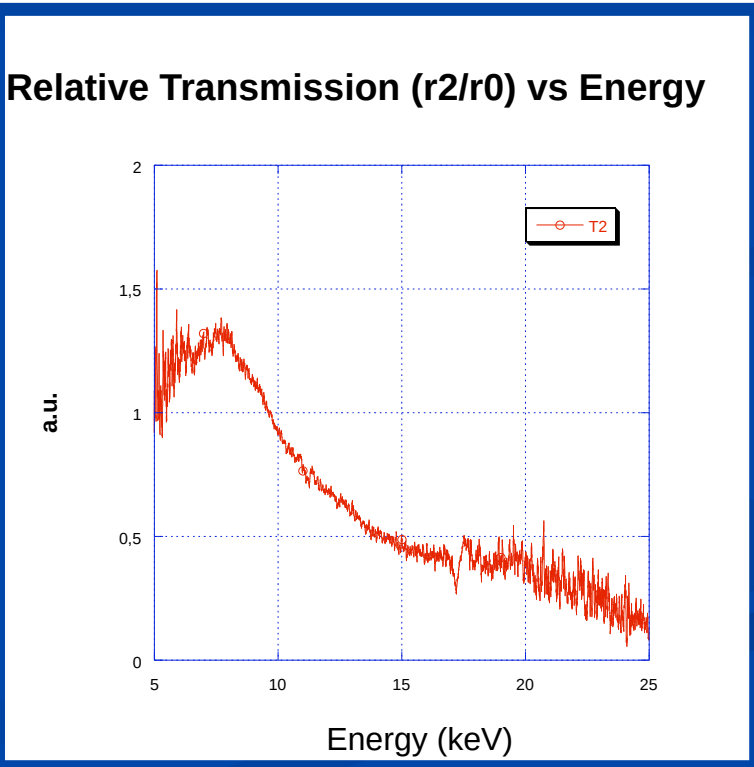
Large Magnification (~ 14)

“Cromatic aberrations”



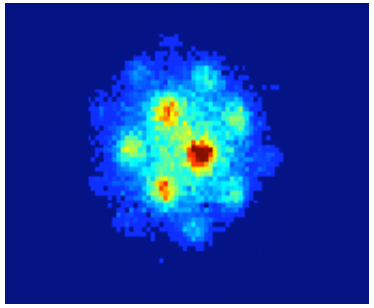


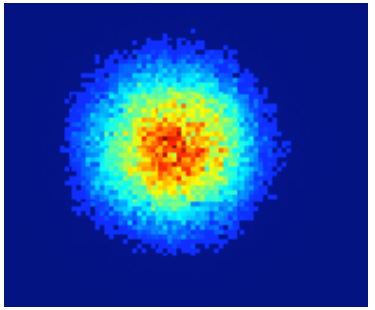




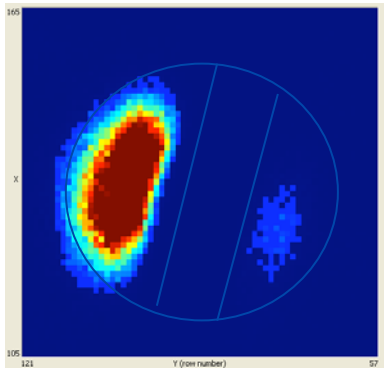
Imaging with half-lens

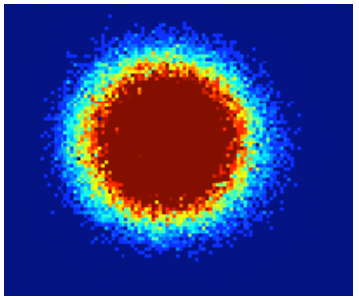
mesh

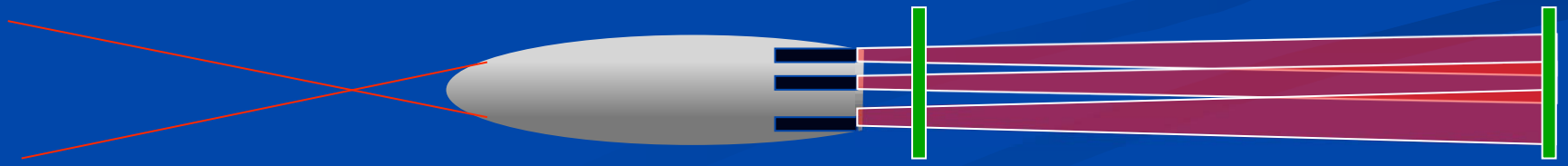




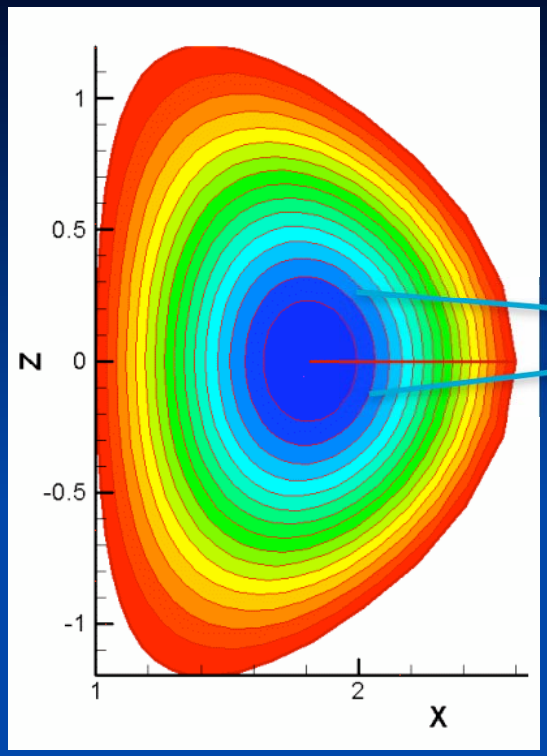
wire



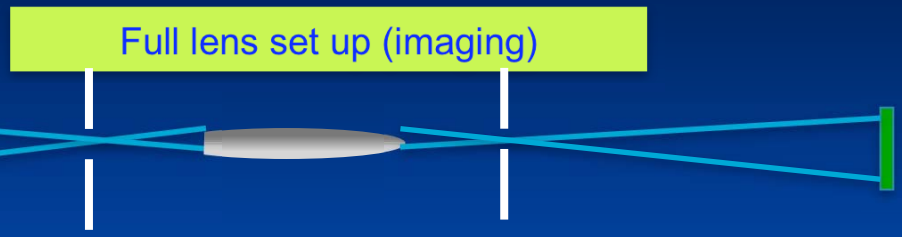




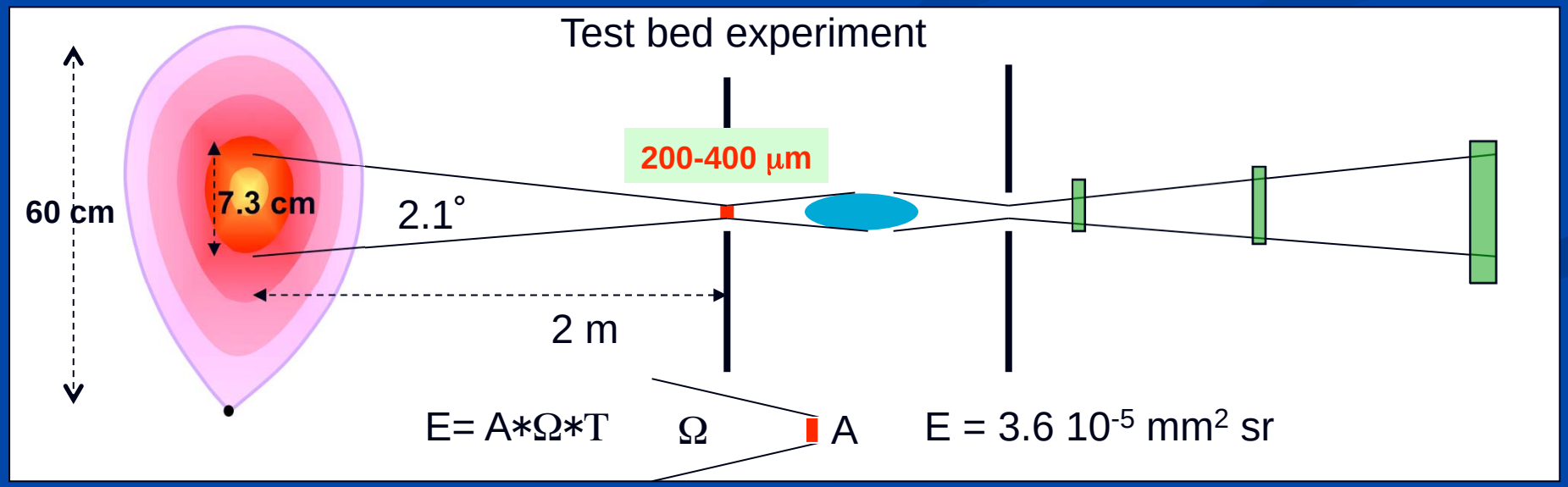
Possible schemes for MCF diagnostics



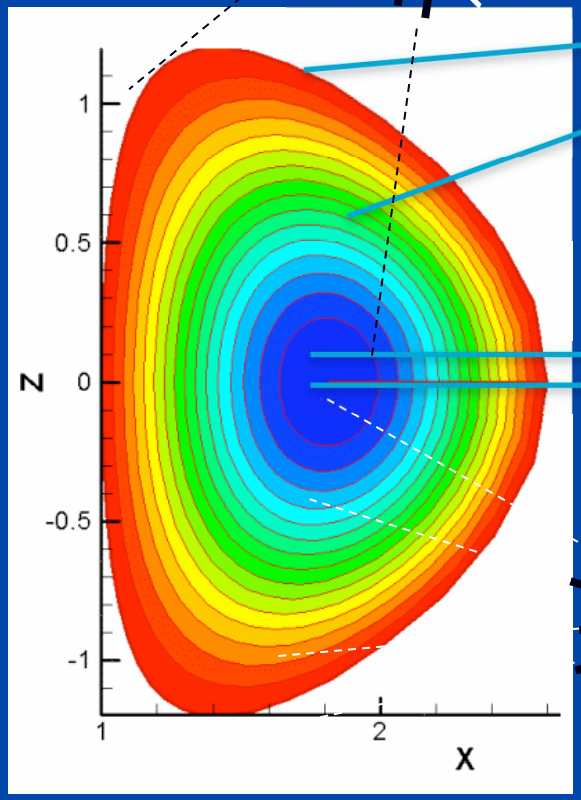
Imaging with magnification (full lens)



Full lens has very good imaging properties, checked up to a resolving power of about 100. Large magnifications



Half-lens is an excellent light collector, very low divergence (quasi parallel beam).
Perfect to move the detector far away.
Pillar (cilindric lens, dia 4-5 mm) is highly directive.
Fibers (straight policapillaries , dia 1 mm) can be bent



detector

Array pillar

"Broad view" collector (half lens)

2-3 °

'Narrow view' collector (half lens)

~ mrad

Tomography array

Array bent fibers

detector

CONCLUSIONS

Optical properties (focus, transmission, optical and chromatic aberrations, divergence) for half lens and full lens have been measured, in the SXR range 5-25 keV

Imaging properties have been demonstrated for full-lens, with a resolving power of about 100, for distances much larger than the focal distance

Polycapillary optics could be very useful for SXR diagnostics (imaging and tomography) for Magnetic Fusion Plasmas.

After these preliminary studies, experiments should be done in a tokamak

Toward Fusion

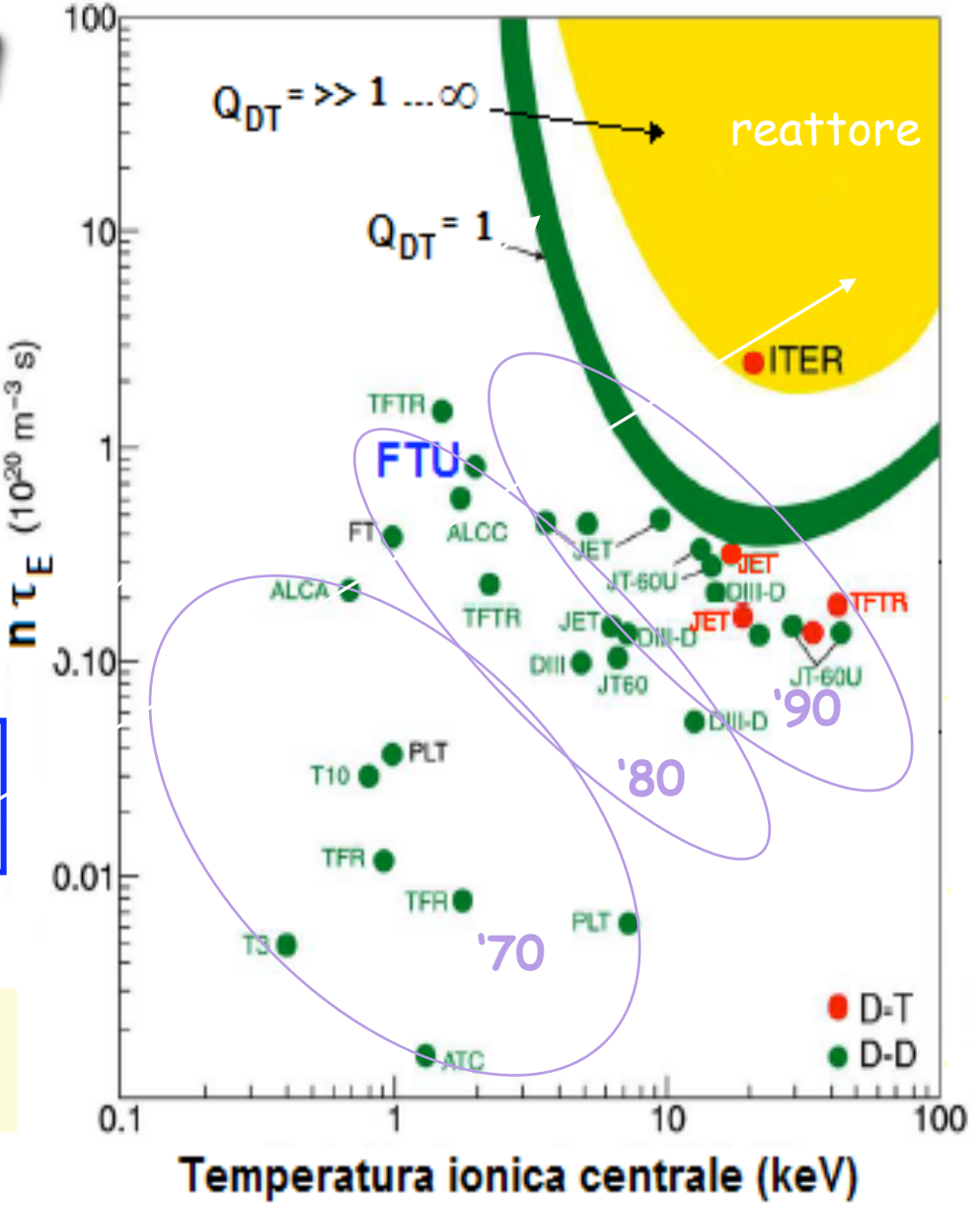
Lawson criterion:

$N \tau_E T > 4\ 10^{21}\ m^{-3}\ s\ KeV$

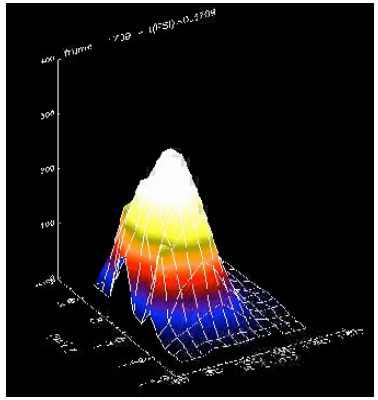
$Q = P_{fusione} / P_{spesa}$

- ★ breakeven => Q=1
- ★ Reactor => $Q \approx 40 - 50$

JET (1997) Q = 0. 65 (transient!)
ITER Q ≈ 5 – 10 (God'will)



Direct SXR imaging range (2 - 8 keV)

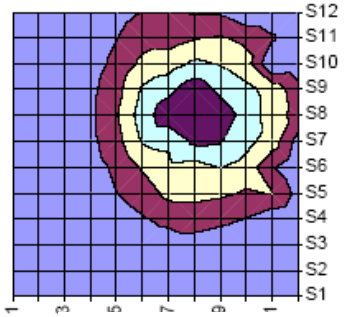


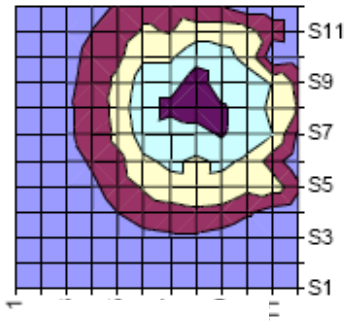
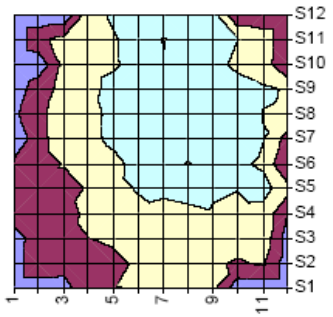
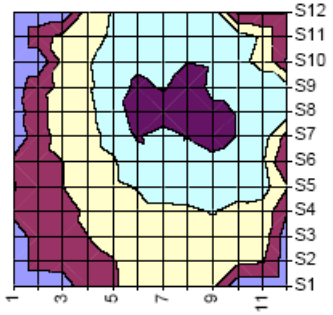
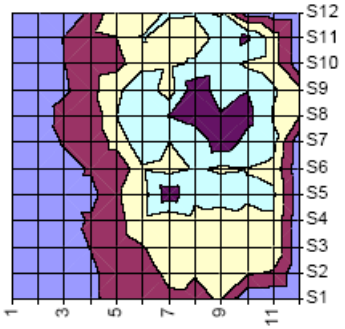
NSTX shot # 107316
Sampling rate = 10 KHz

SXR imaging in MCF requires low spatial resolution (RP =a/Δx = 10-100) and high framing rate (1-100 kHz)

Direct SXR imaging

Wide view (80x80 cm) # 107314





Zooming (40x40 cm) # 107390