Photons ?

Max Planck in 1913, when he nominated Einstein for membership in the Prussian Academy of Science in Berlin:

"Summing up, we may say that there is hardly one among the great problems, in which modern physics is so rich, to which Einstein has not made an important contribution. That he may have sometimes missed the target in his speculations, as, for example, ***in his hypothesis of light quanta (photons),*** *cannot really be held too much against him, for it is not possible to introduce fundamentally new ideas, even in the most exact sciences, without occasionally taking a risk."*

Time-resolved, low-level light imaging for security applications

V. Dangendorf, **PTB Braunschweig, Germany**

with:
D. Vartsky, Soreq NRC, Yavne, Israel
A. Breskin, Weizmann Inst, Rehovot, Israel
O. Jagutzki, Roentdek GmbH, Kelkheim, Germany
M. Riches, Invisible Vision Ltd, Norwich, UK

Soreq NRC

Large Photon-Detector Arrays for Homeland Security Applications

Needs and Trends

D. Vartsky, *Soreq NRC, Yavne, Israel*

R. Kouzes, *Pacific Northwest National Laboratory, U.S.A.*

LIGHT06
Eilat, Israel
January 2006

Detection of Explosives @ Light06

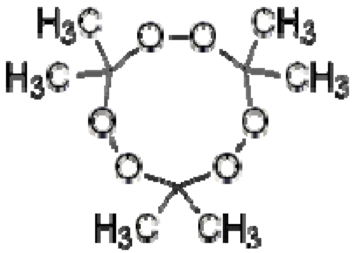
- Pulsed Fast Neutron activation (PFNA)
- Gamma Resonance Absorption (GRA)
- Pulsed Fast Neutron Transmission Spectroscopy (PFNTS)

PFNTS :

- Application
- Method
- Detectors for time resolved fast neutron imaging
- Requirements for light detection and imaging

Detection of standard and improvised explosives

TATP - $C_9H_{18}O_6$
(triacetone triperoxide)



- High explosive which can be made from common household items: acetone, hydrogen peroxide and sulfuric acid

- TATP does NOT contain nitrogen !

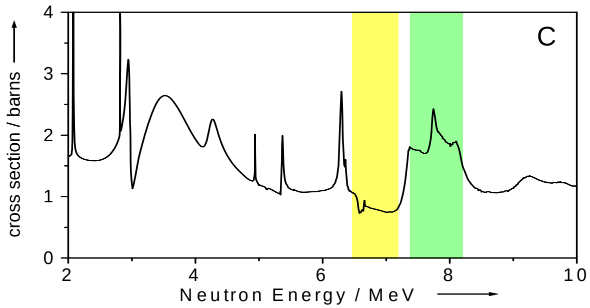
- Highly sensitive to heat, friction, and shock („Mother of Satan“, frequent „work accidents“)

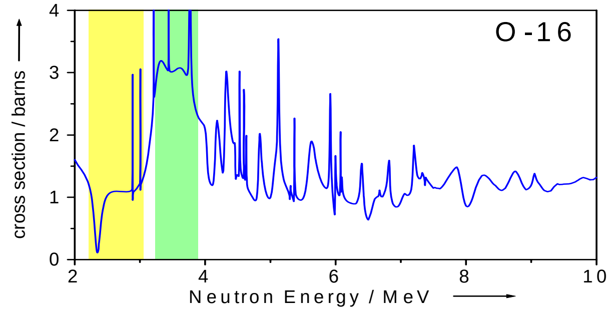
- Used by suicide bombers against Israeli civilians

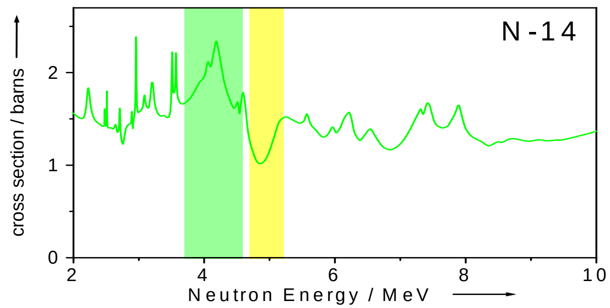
- 2005 UK railway-bomber, 2006 attempt at Heathrow Airport and 2 weeks ago in the thwarted attack in Germany

Pulsed Fast-Neutron Transmission Spectroscopy

Principle: Fast-N **Radiography**, exploiting fluctuations in cross-section to detect objects that contain specific elements







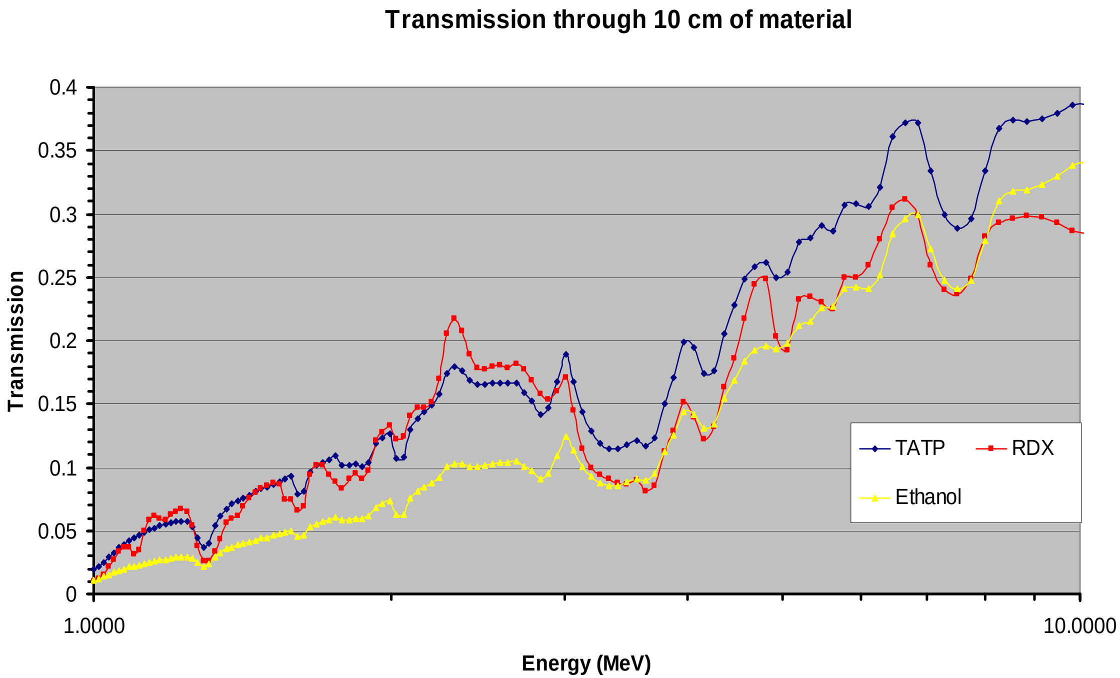
Pioneered: University of Oregon (1985-1992), Tensor Technology (since 1992)

Applications include :

- Cargo and baggage inspection - measuring C, N, O distribution (explosives, drugs)
- Detection of diamonds within mineral matrix (De Beers, South Africa)

Pulsed Fast Neutron Transmission Spectroscopy

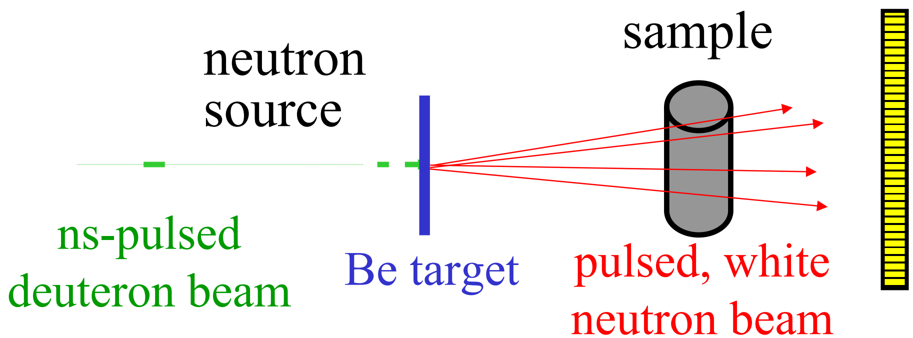
TATP- $C_9H_{18}O_6$ **RDX** - $C_3H_6N_6O_6$ **Ethanol** - C_2H_6O



Measurement of neutron energy is <u>prerequisite</u> for Resonance Imaging

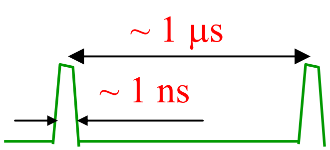
Principle of PFNTS

Multiple Transmission Images with Neutron Energy selected by Neutron Time-Of-Flight (TOF)



Neutron Imaging Detector with fast timing capability !

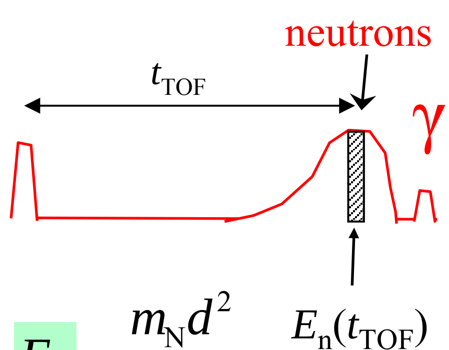
- Intense pulsed deuteron beam (12 MeV, 50-200 µA) hits solid Target (e.g Be)
- pulsed, broad energy neutron beam (1 – 10 MeV)
- neutron TOF ⇒ neutron energy
- need for imaging system with fast (ns !) timing capability



deuteron pulses:

1 ns wide,

>0.5µs distance



$$E_N = \frac{m_N d^2}{2 \cdot t_{TOF}^2}$$

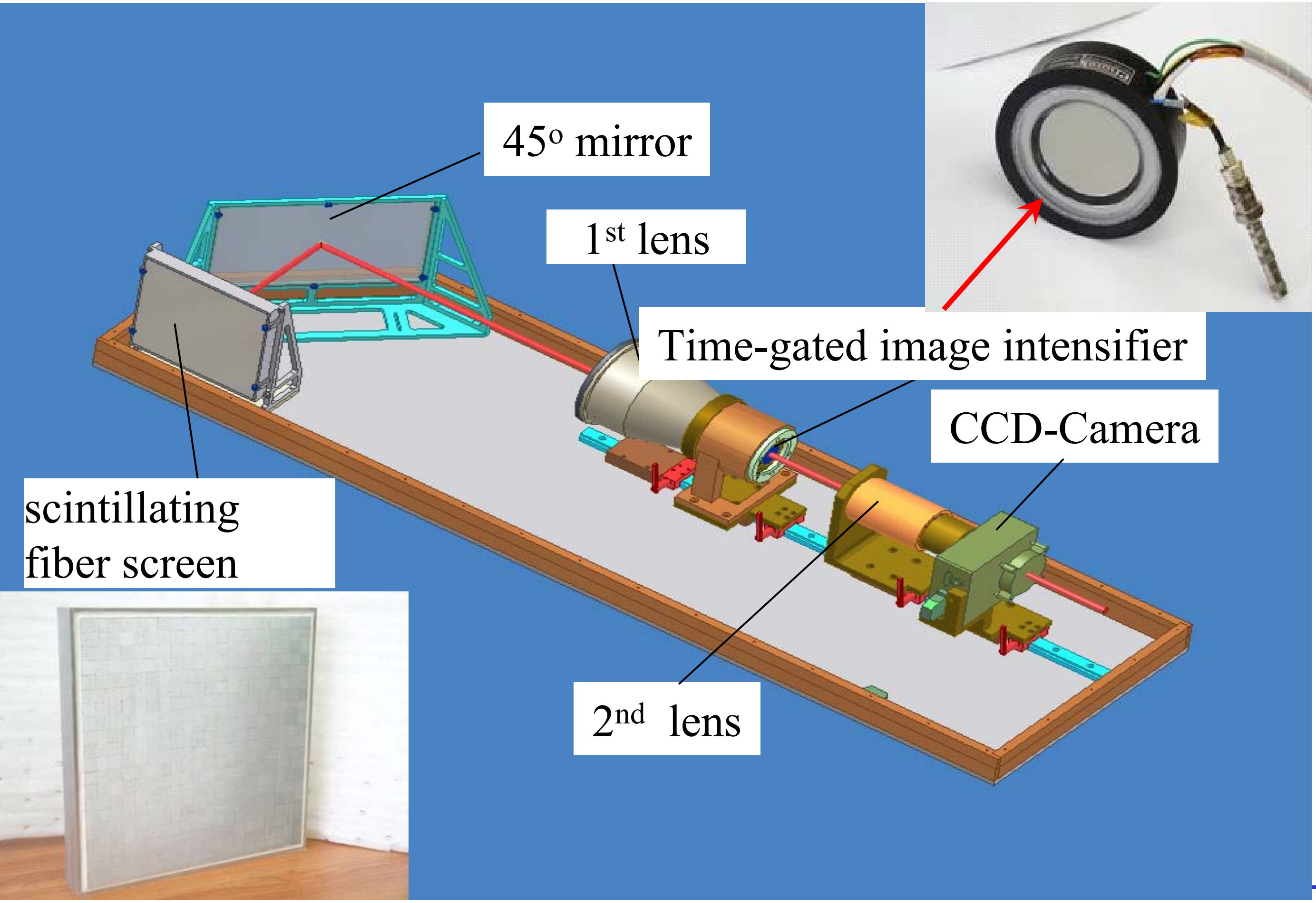
Neutron Detectors for PFNTS

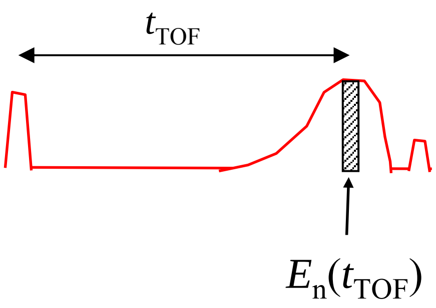
Detector requirements

- Large area: **>50x50 cm^2**
- High detection efficiency for MeV neutrons: **10-15%**
- High counting rate capability: **> 10^4 s^{-1}mm^{-2}**
- Neutron spectroscopy in **2 - 12 MeV** range
- Energy resolution: **~ 500 keV** at **8 MeV**
- Position resolution: **~ 1 mm**

Neutron Detectors for PFNTS

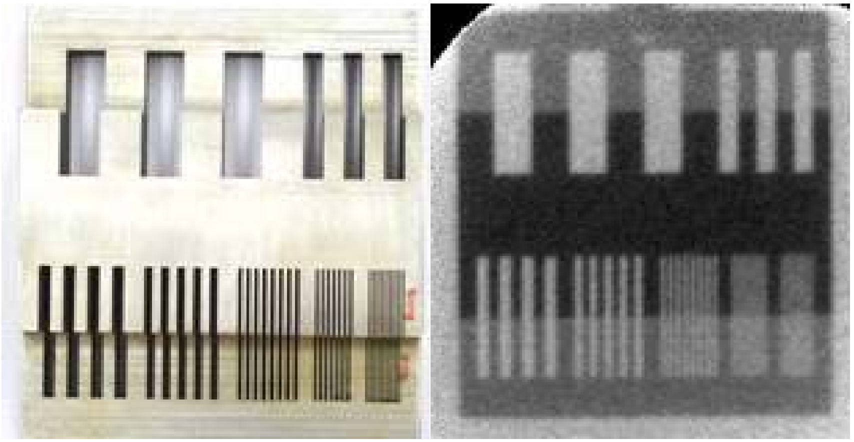
Integrating Fast-Neutron Imaging System



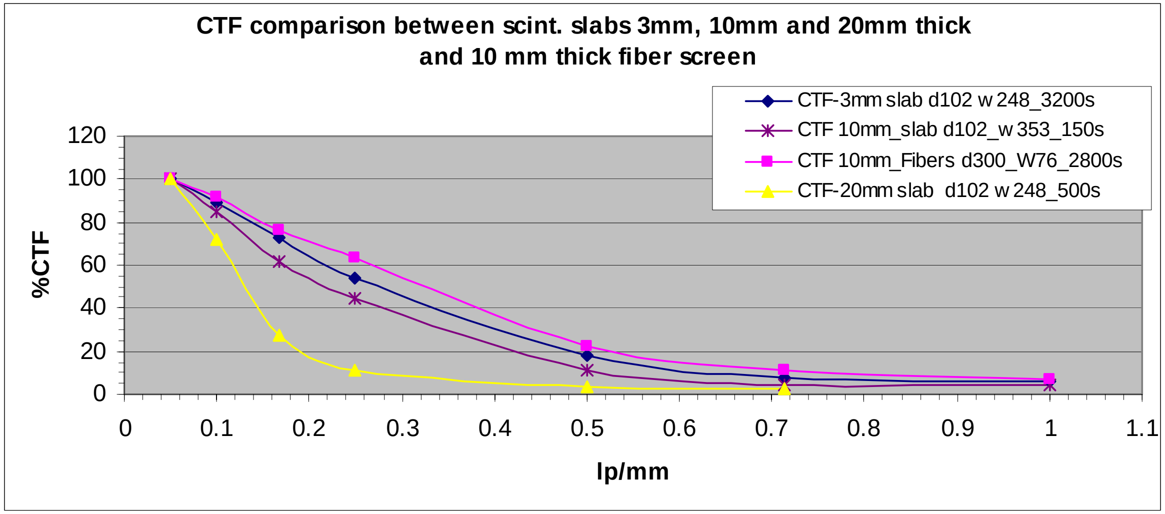


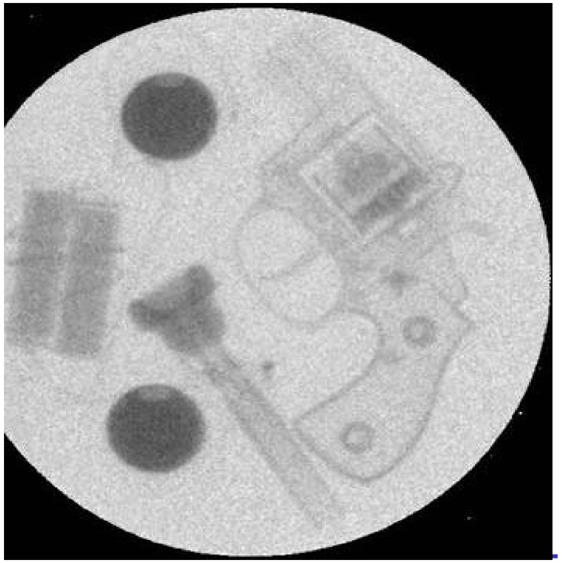
Spatial-Resolution

(August 27, 2005)

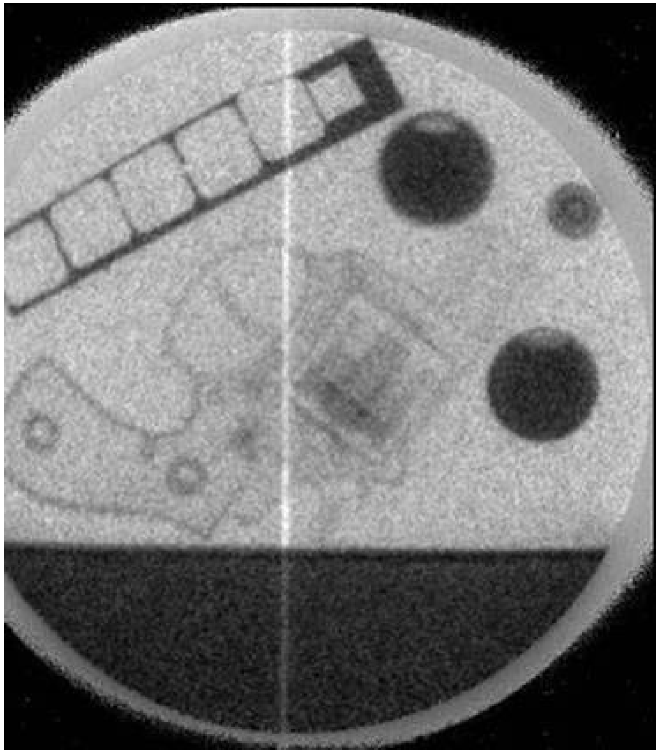


Steel mask and its fast neutron image



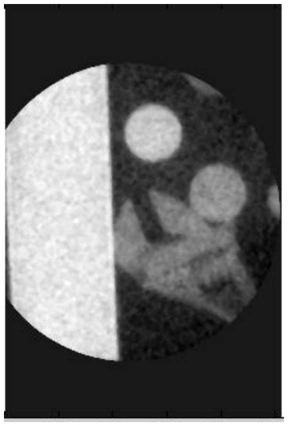


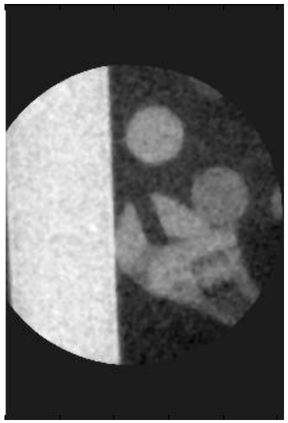
Objects, shielded by a 1” thick lead bricks

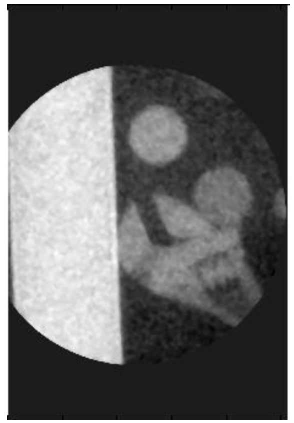


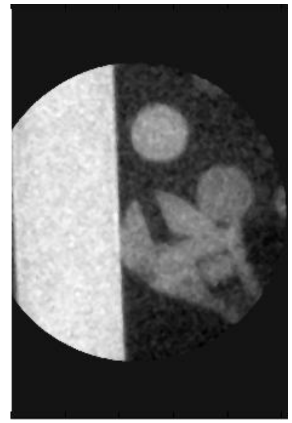
Fast neutron image, 1 – 10 MeV

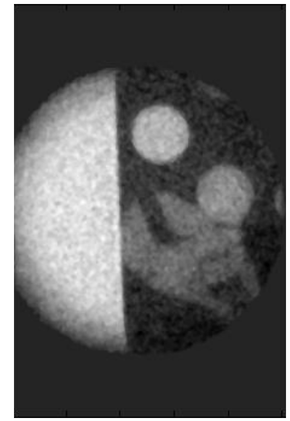
Elemental Imaging
(from camera images for different TOF bins)

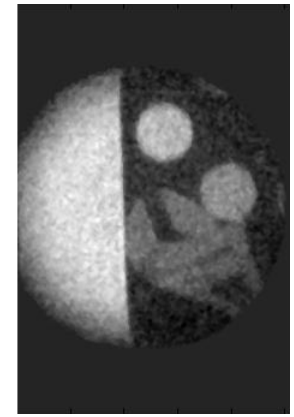

180 ns

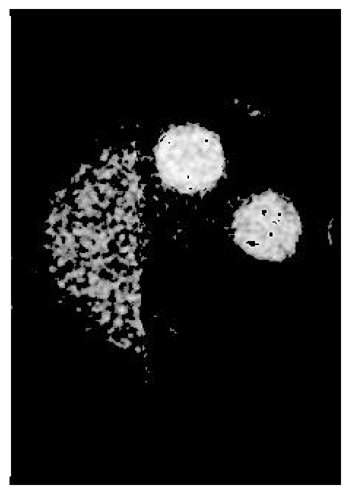

200 ns

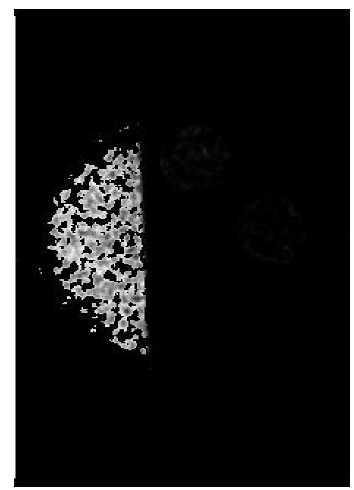

210 ns


230 ns

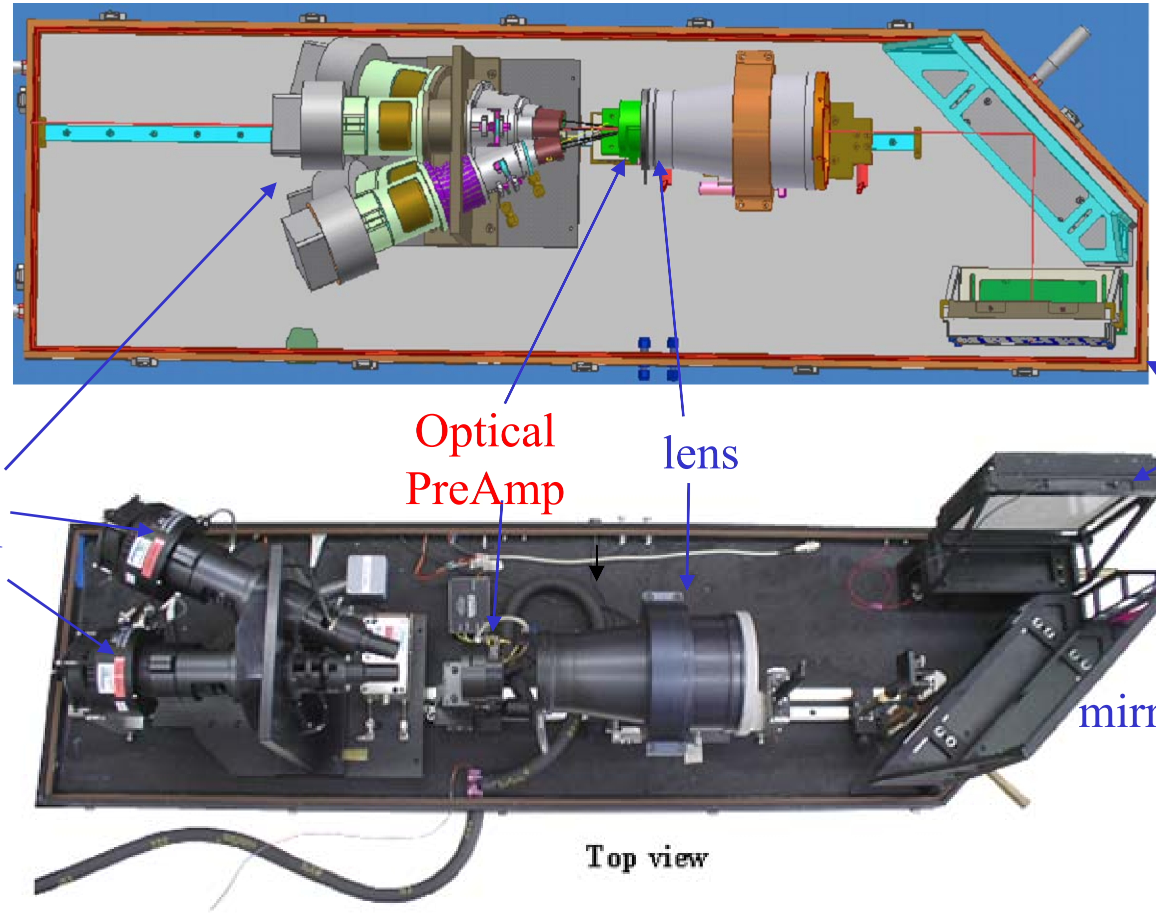

320 ns


330 ns

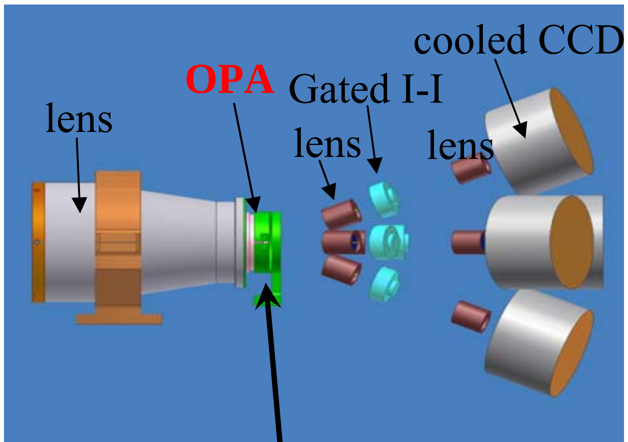

C image


N image

Simultaneous Imaging at several Energies with Optical Booster and Multiple Intensified Cameras



Optical Preamplifier (OPA)

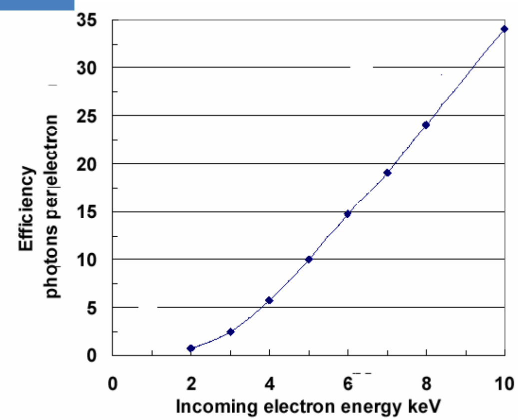


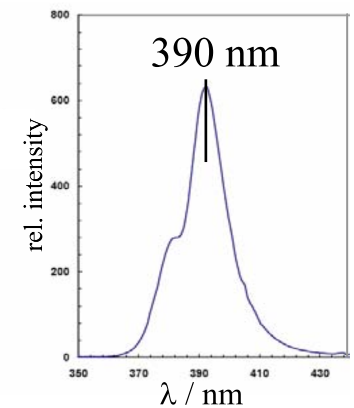
"standard" ∅ 40mm Photek image intensifier with Chevron MCP

but:

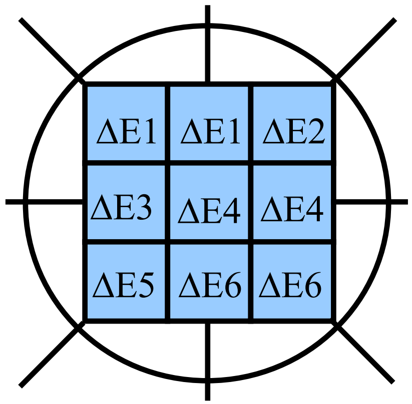
fast phosphor E36 from ElMul:

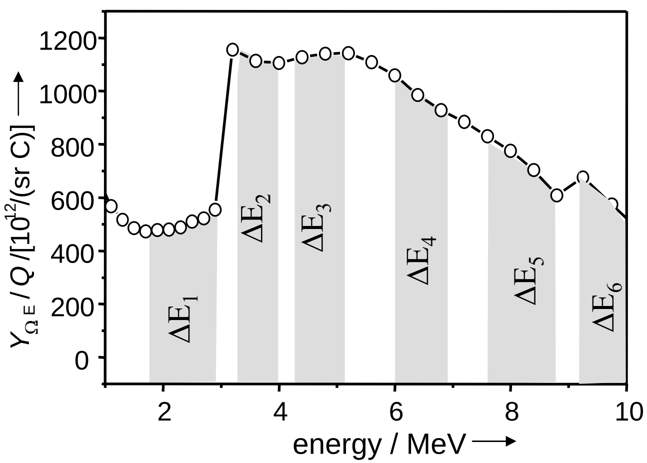
decay time 2.4 ns





Multiple Energy Imaging with Fast Framing Techniques



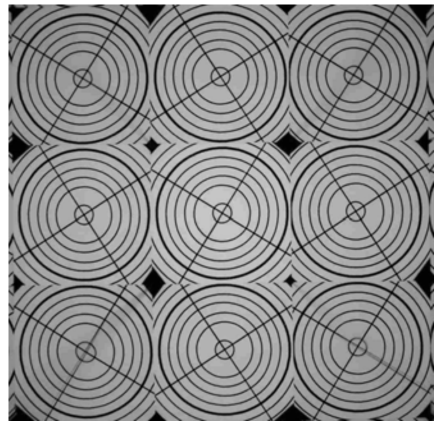


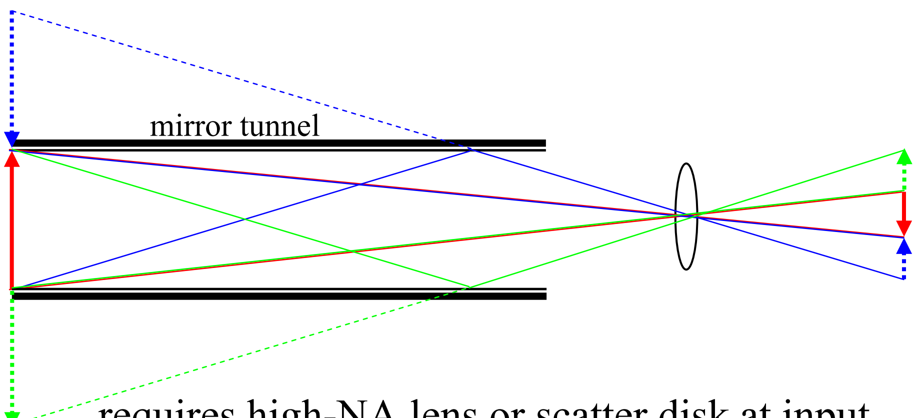
High speed camera Ultra8 (DRS Hadland):

8 frames, independently gateable with few-ns wide pulses

proposed and tested for PFNTS in 2002 but without success

Fast Framing Camera
Image Splitter





requires high-NA lens or scatter disk at input

Here light from OPA "fills" the tunnel

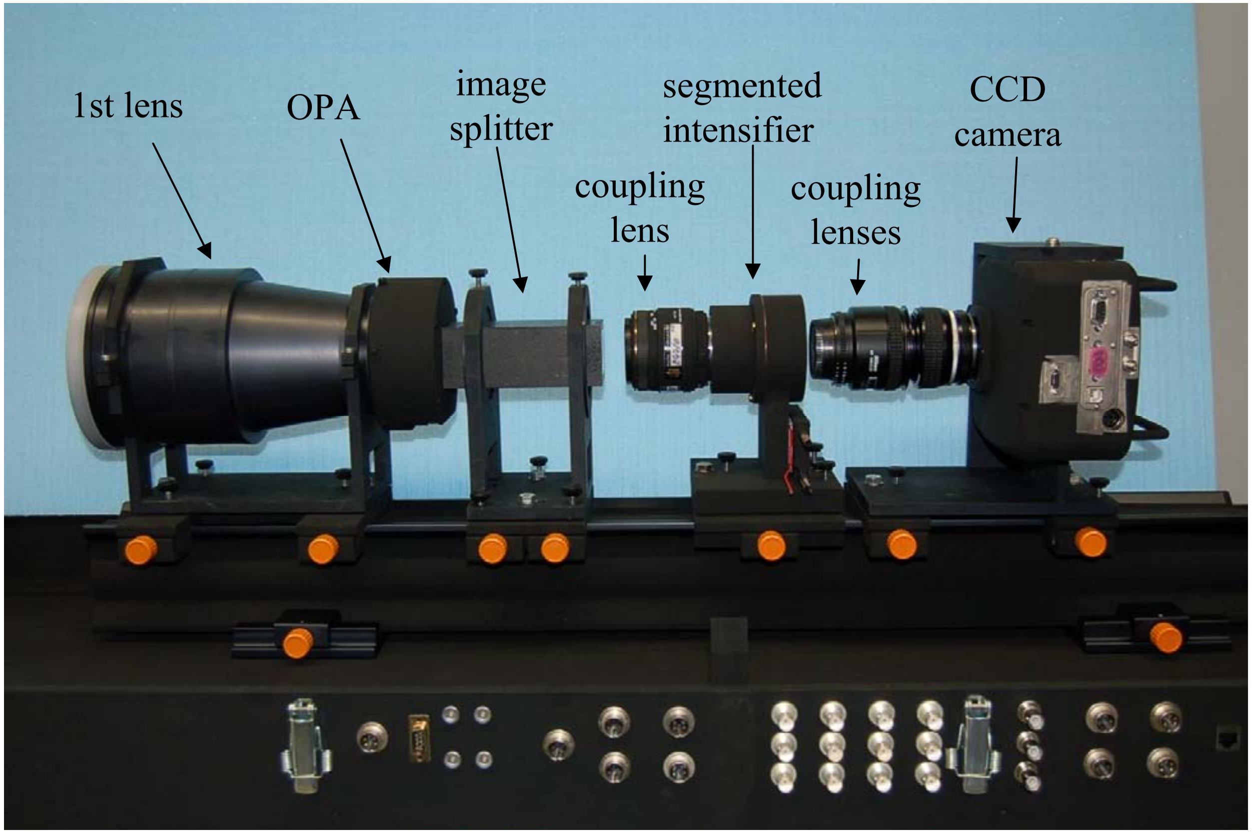
Method:

kaleidoscope-like mirror tunnel projects 9 (or more) identical images onto a segmented image intensifier

patented by M. Riches

Invisible vision

Fast Framing Camera with SI in progress



Fast Framing Camera Stumbling Blocks

Optical Preamplifier (booster):

Collaboration between manufacturers causes frictions

Optimisation: light output of phosphor, gain of tube, custom made flanges (desirable is a 2 mm thick output window)

High QE (35 – 40 %) photocathodes desirable

Gated Segmented Intensifier:

Heating @ 2 MHz may cause noise problem and might harm PC

QE of present SI: 1 - 3 % @ 390 nm.

Desirable: quartz-fiber input optics, grid underneath PC (instead of metal layer)

FAST-NEUTRON IMAGING WITH A PULSE-COUNTING IMAGE INTENSIFIER (PCII)

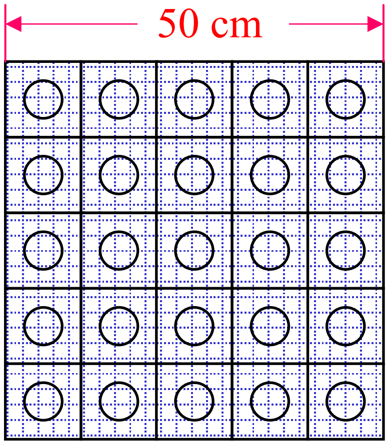
Combining optical with pulse counting system

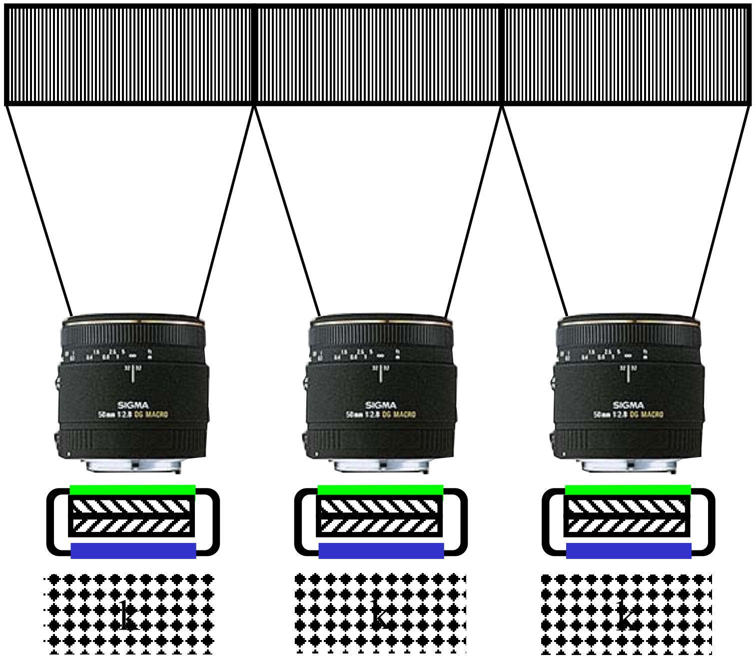
Benefits:

- Large efficiency and good intrinsic position resolution by thick scintillating fibre screen
- Optical readout by a pulse counting image intensifier allows position and high resolution ToF measurement
- Transversal segmentation enables high rate operation and flexible screen geometry (square, line)

Model of a Large Area Fast-Neutron Camera with a PCII

1 module consists of:
- scintillating fibre screen
  e.g. 25 units size 50 x 50 x 30 mm^3
- Lens
  (e.g. standard 50 mm macro lens)
- Pulse counting image intensifier





Array of 5 x 5 modules, each 100 cm^2 ,
views area of 50 x 50 cm^2

PCII with internal Delay-Line Readout

(Roentdek, Photek)

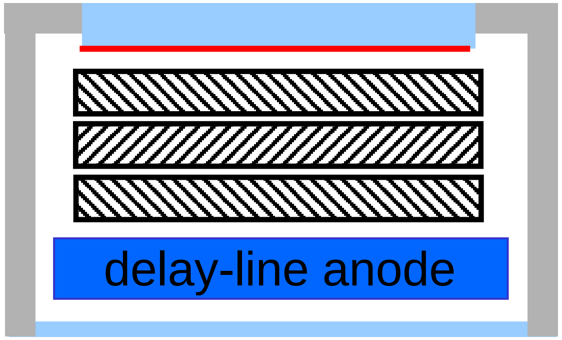
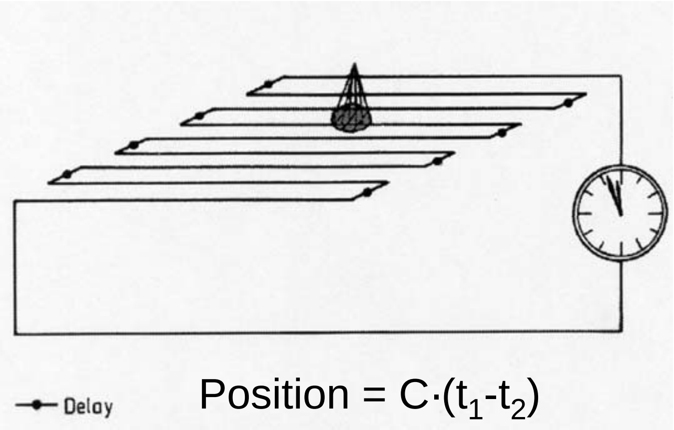
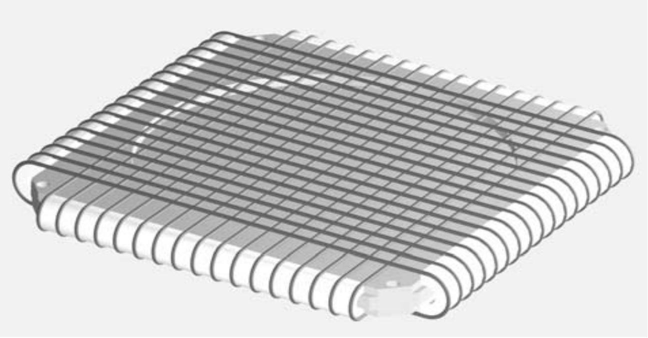


photo- cathode

MCP Z-stack

R/O anode
(int. Delay line





Helical wire delay-line anode

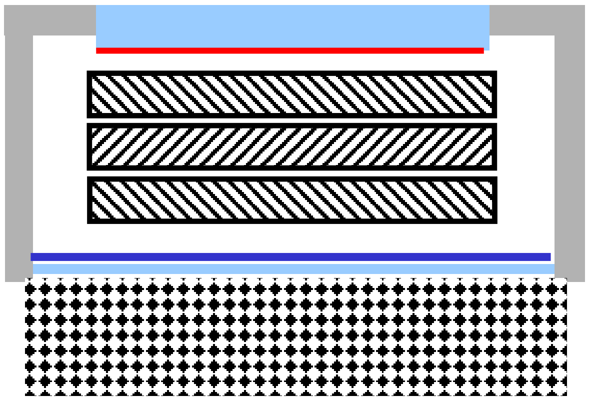
Properties:

- well suited for low light intensities up to a few MHz
- excellent position resolution (25 µm RMS)
- timing resolution better than 125 ps RMS
- virtually no dead time (only if DR > 7mm on MCP)
- complicated (nonstandard) production process

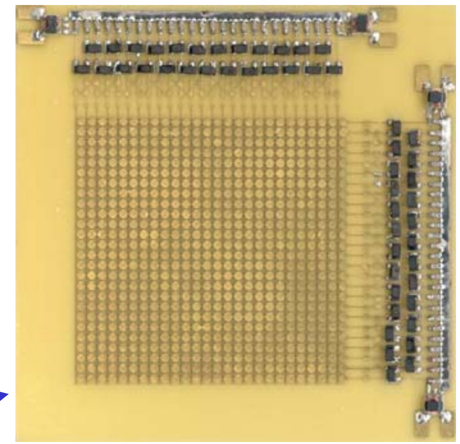
next page

PCII with external Delay-Line Readout

(Roentdek, Proxitronic, (Burle ?))



2-d position sensitive
readout board
(outside of tube!)



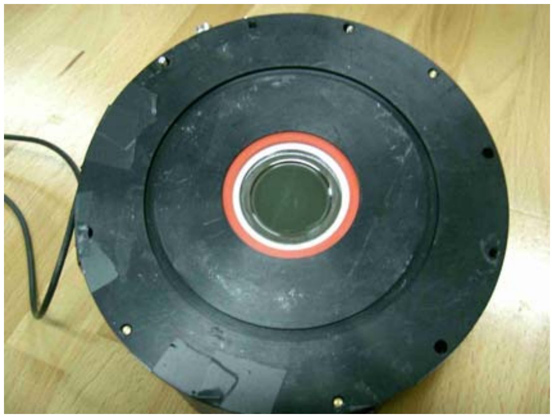
Properties:

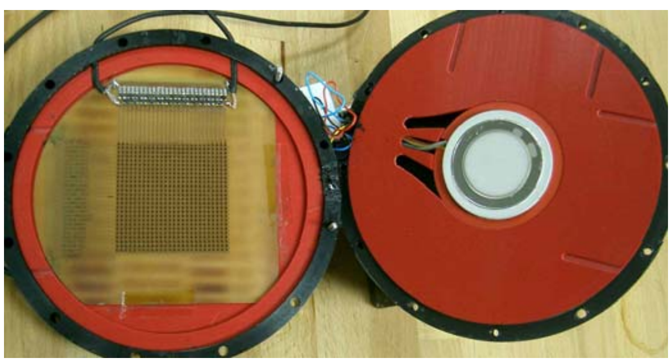
- cheap and robust
- resolution in time (<125 ps RMS)
- position resolution 50 µm RMS)
- dead time < 60 ns

High resistivity anode enables position sensitive signal induction to external RO board !

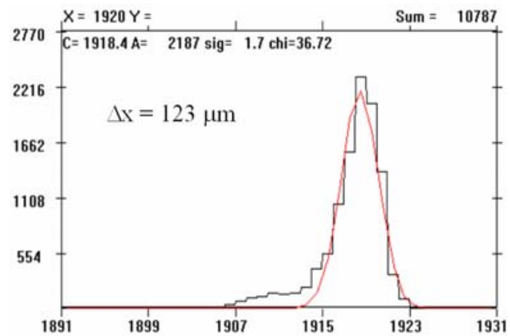
next page

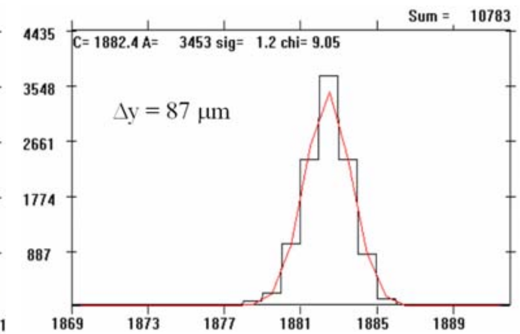
Pulse Counting Image Intensifier



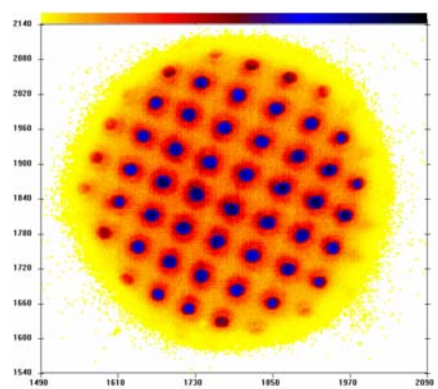


position resolution (> 1000 photo e$^-$ / pulse)

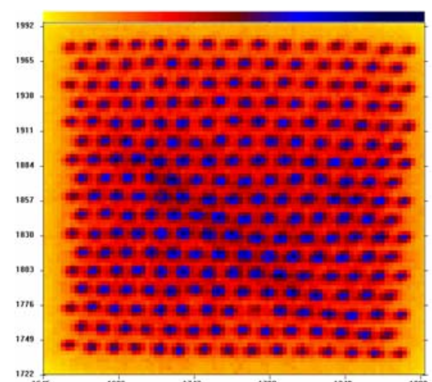




optical images with single photo-e$^-$



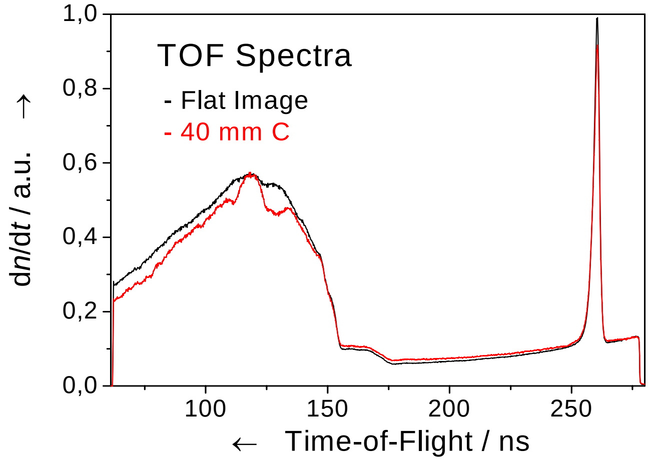
∅ 0.95 mm, d = 2.7 mm

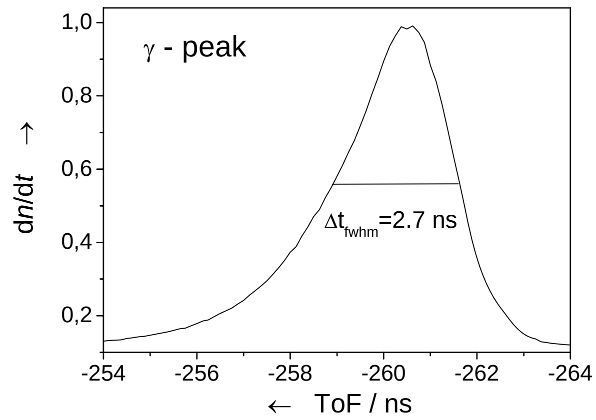


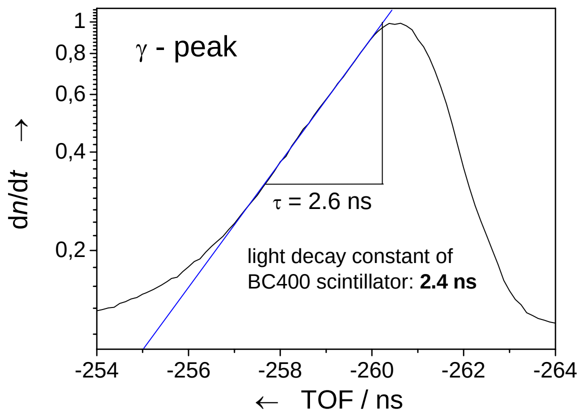
∅ 0,3 mm, d = 0,7 mm

Spectroscopic Neutron Imaging
Time Resolution

Time-of-Flight spectra

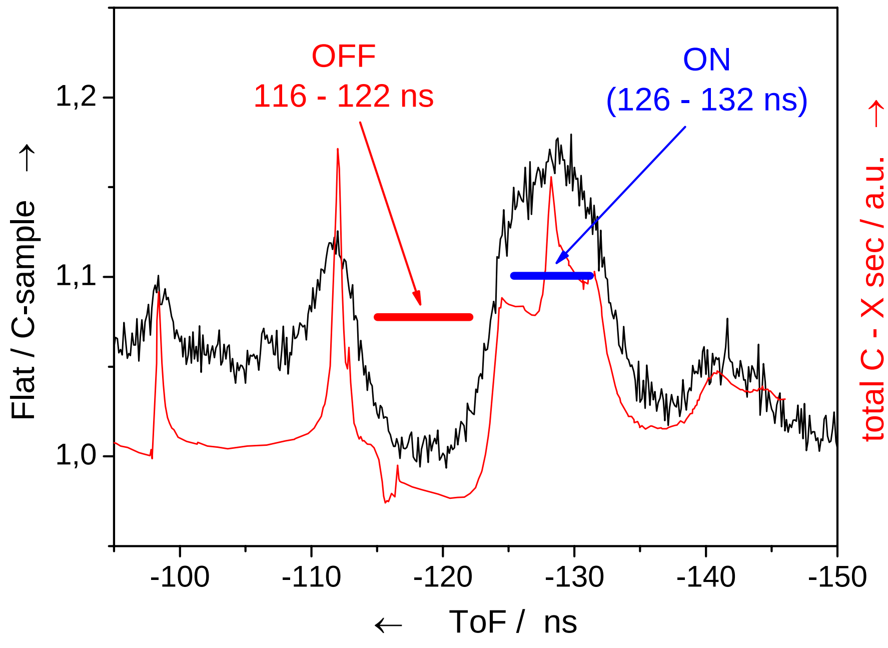




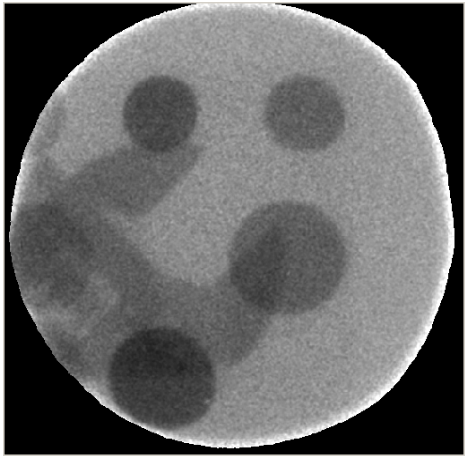


Spectroscopic Neutron Imaging
Neutron TOF

Ratio: Sample/Flat:



ON



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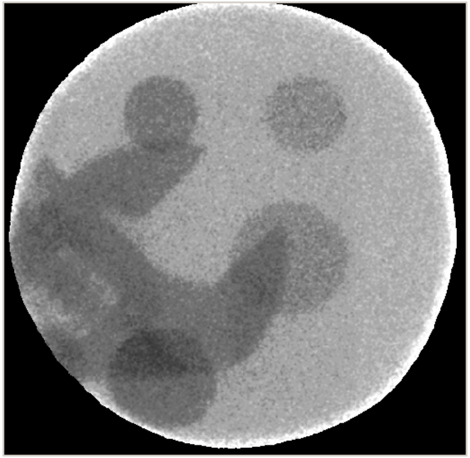
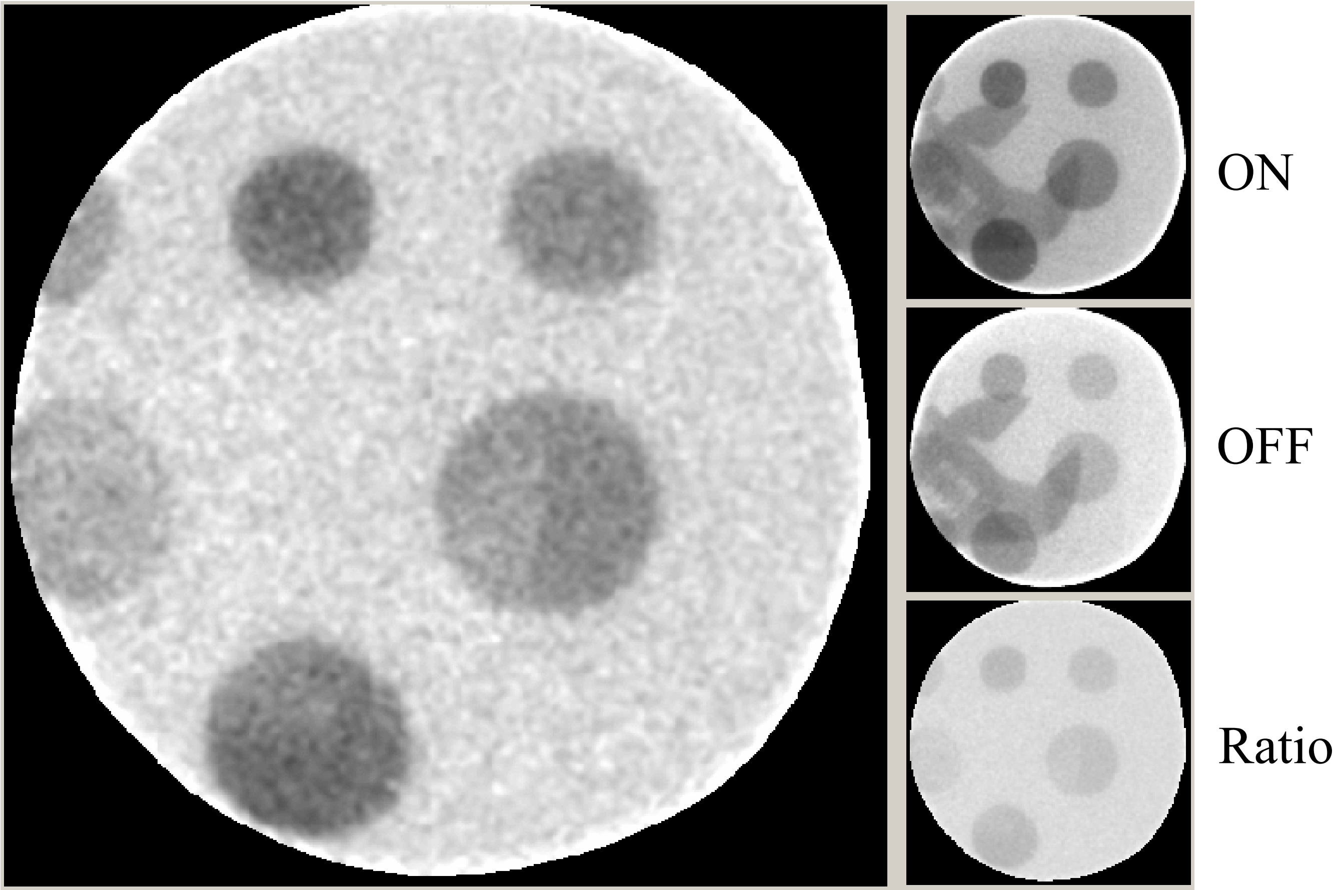
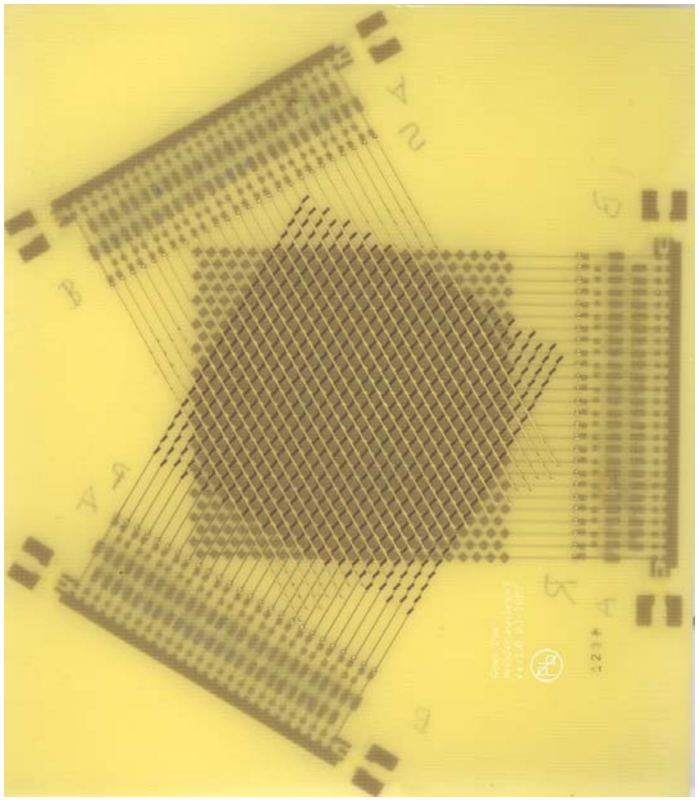


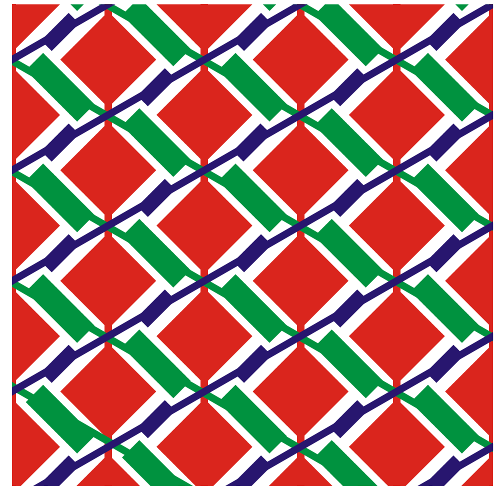
Spectroscopic Neutron Imaging



Multihit Imaging with Hexagonal Delay-line Structures



printed delay line structure with 3 layers



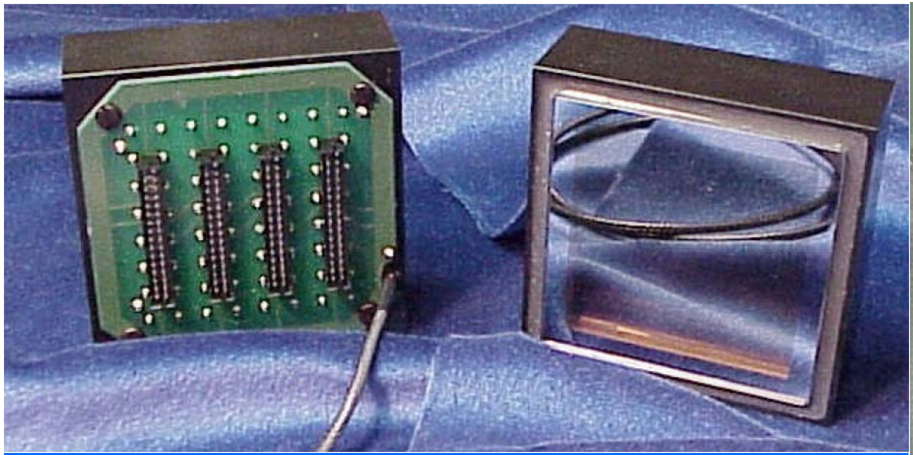
Advantages:

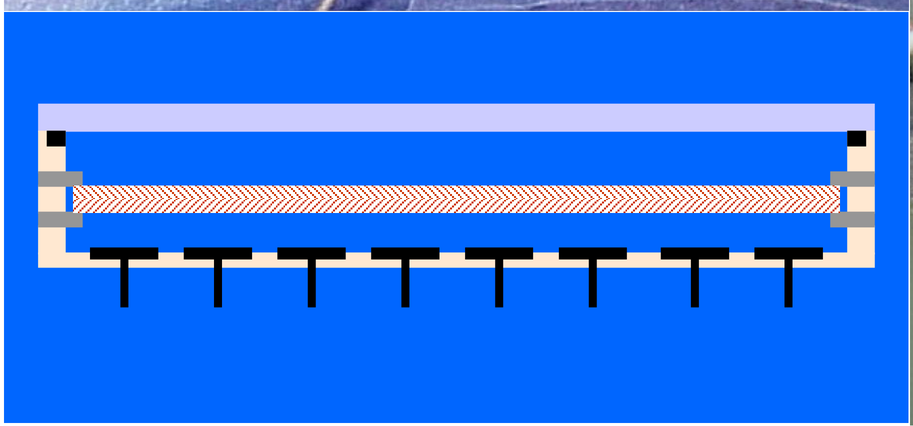
- Multihit capability
- reduced dead time (due to redundancy)
- correction of non-linearities
  using redundant data

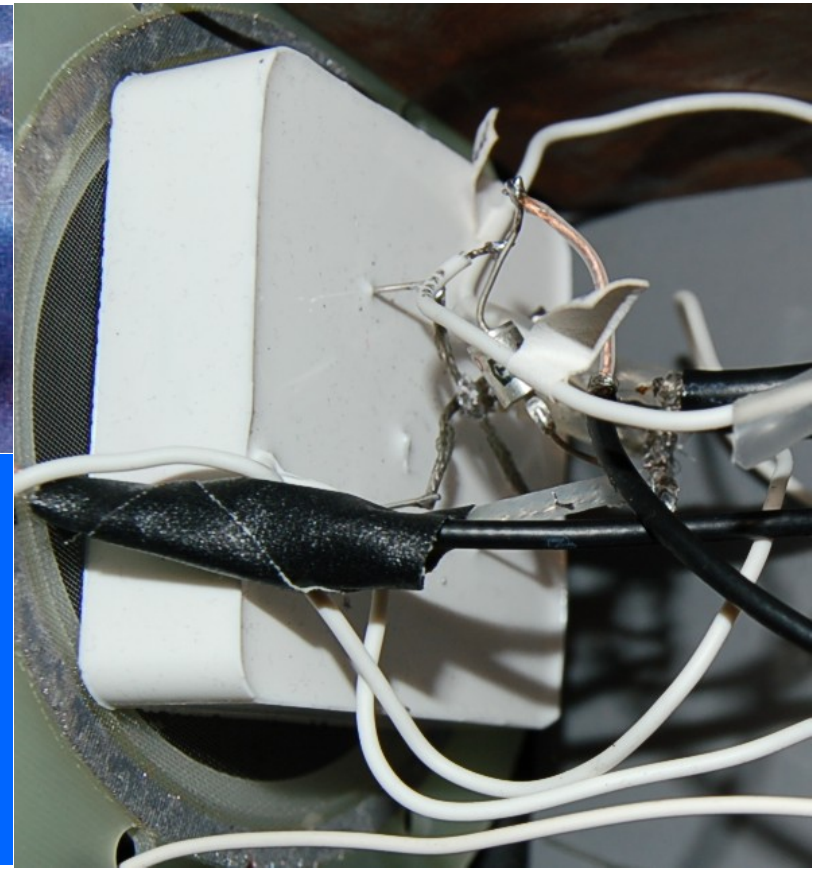
From: SPIE Optics East 6771-31   10. Sep. 2007   A. Czasch

Hot Candidate for future PCII

Variant of Burle's Planacon with Ge-anode







Further Information
see Poster

Position- and time-sensitive photon-counting detectors with delay-line read-out

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[2] Physikalisch-Technische Bundesanstalt, Abteilung Neutronenphysik, 38116 Braunschweig, Germany
[3] Photek Ltd., 26 Castleham Road, St. Leonards on Sea, East Sussex, TN38 9NS, UK

Contact:
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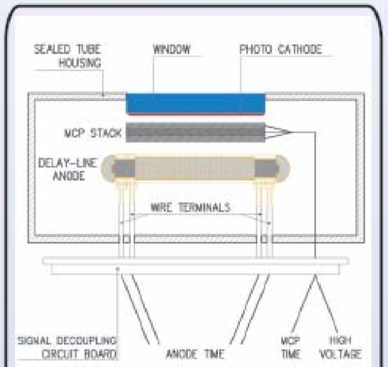
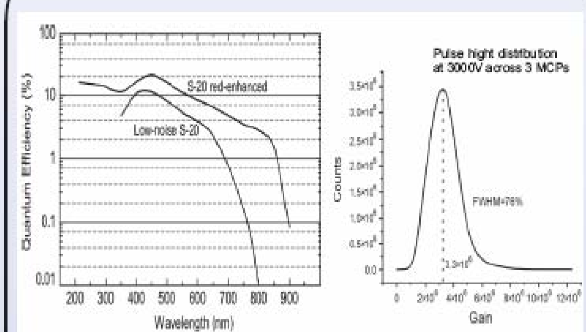
MCP PHOTO-MULTIPLIER TUBE WITH HELICAL-WIRE DELAY-LINE ANODE (DL-PMT)

Introduction

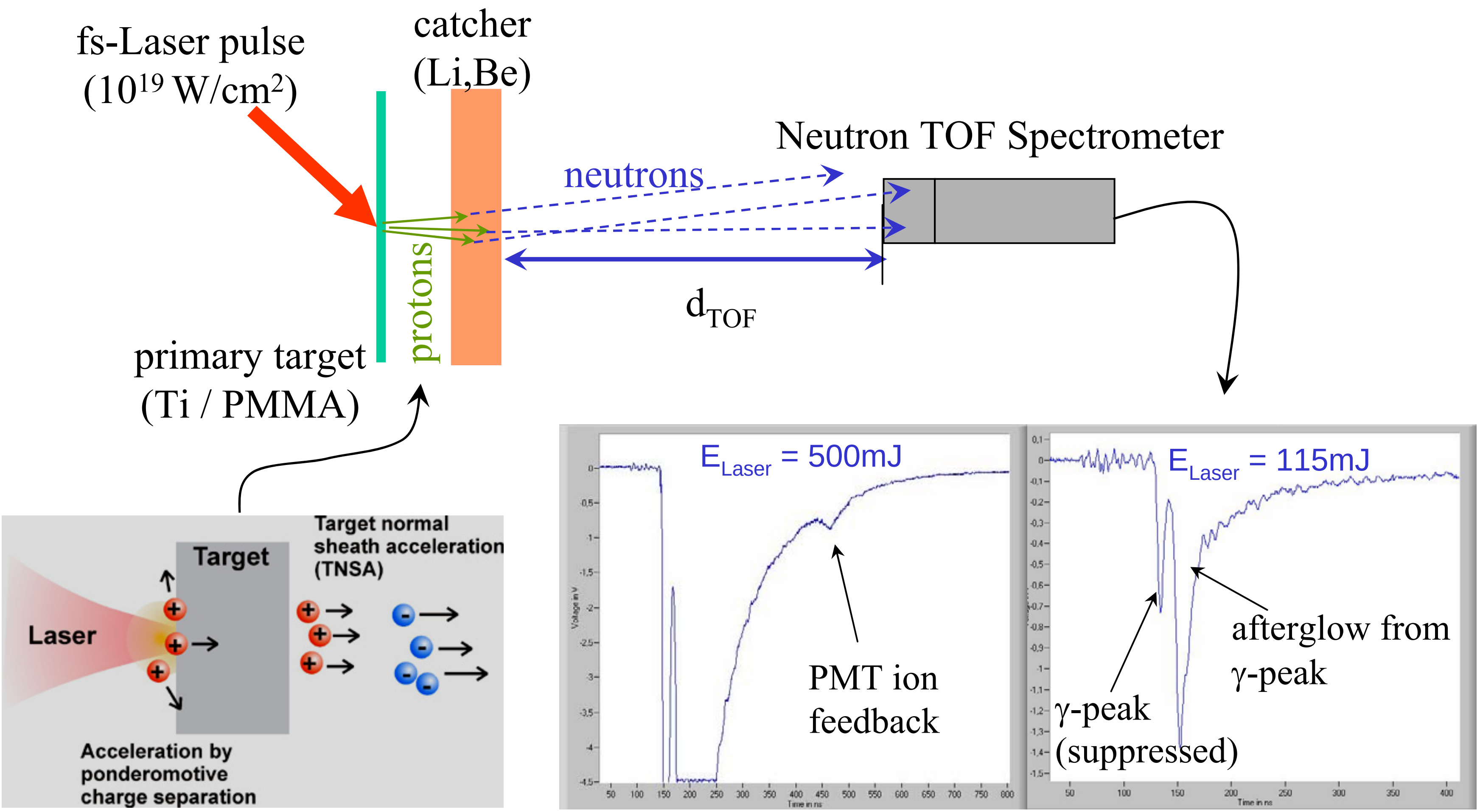
- We have combined standard photo multiplier techniques (MCP and photo cathode) with delay lines for a fast high resolution time- and 2D-position readout.
- Two types of detectors - one with helical-wire delay line (DL-PMT) inside the sealed housing and the other with a charge-coupled printed delay line at atmosphere (RS-PMT) - were produced.
- Due to precise time tagging (< 1 ns), high position resolution (< 0.1mm) for single photon detection and negligibly low background this technique is especially suited for low light applications.





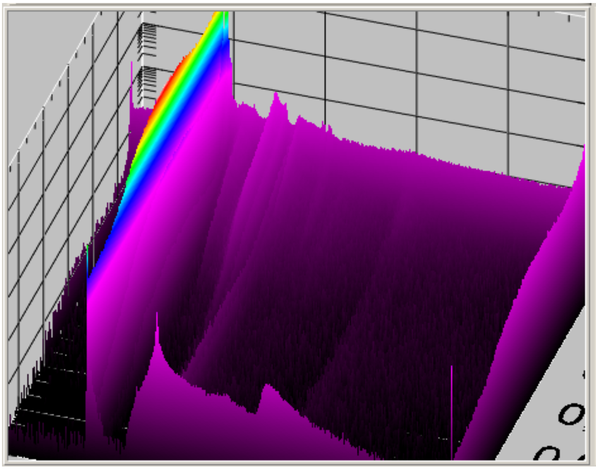
Quantum efficiency of two different photo cathodes on

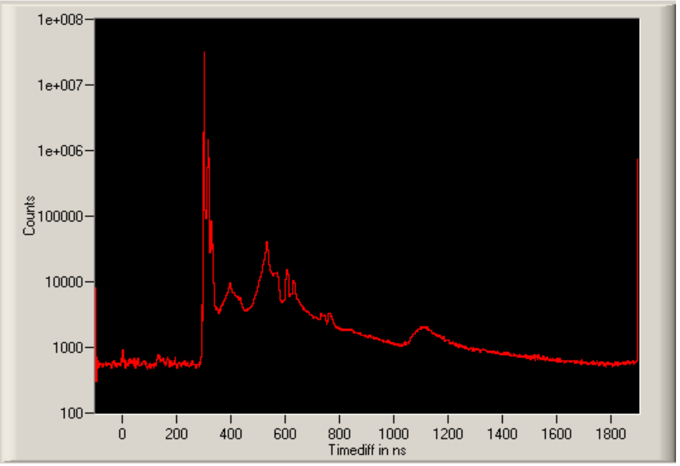
High-Power Lasers for Future Pulsed-Neutron Sources ?



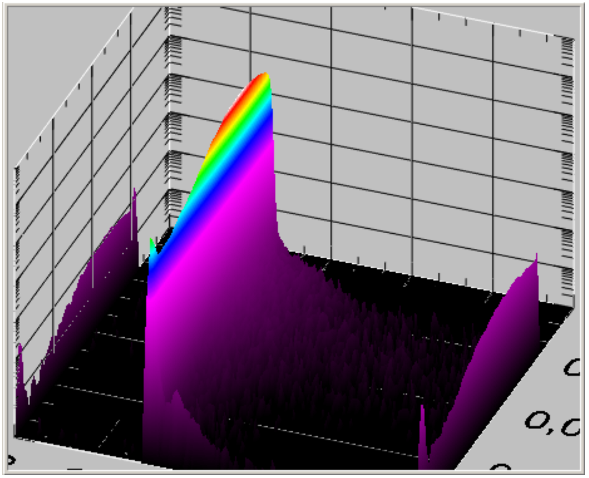
Selection of Low Ion-Feedback PMT

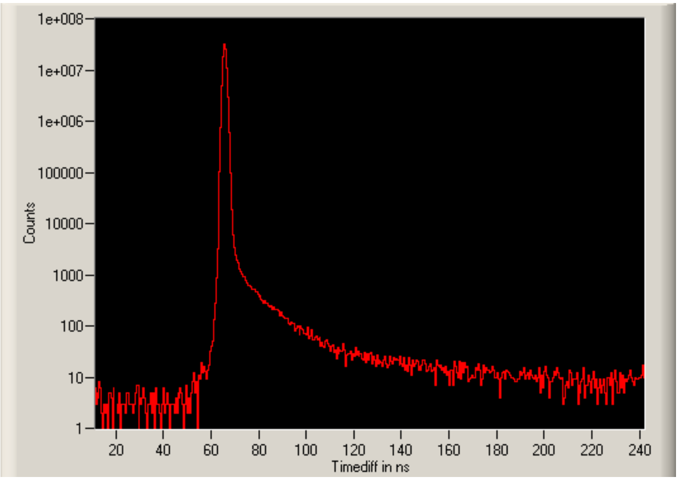
XP2020:
(Photonis)



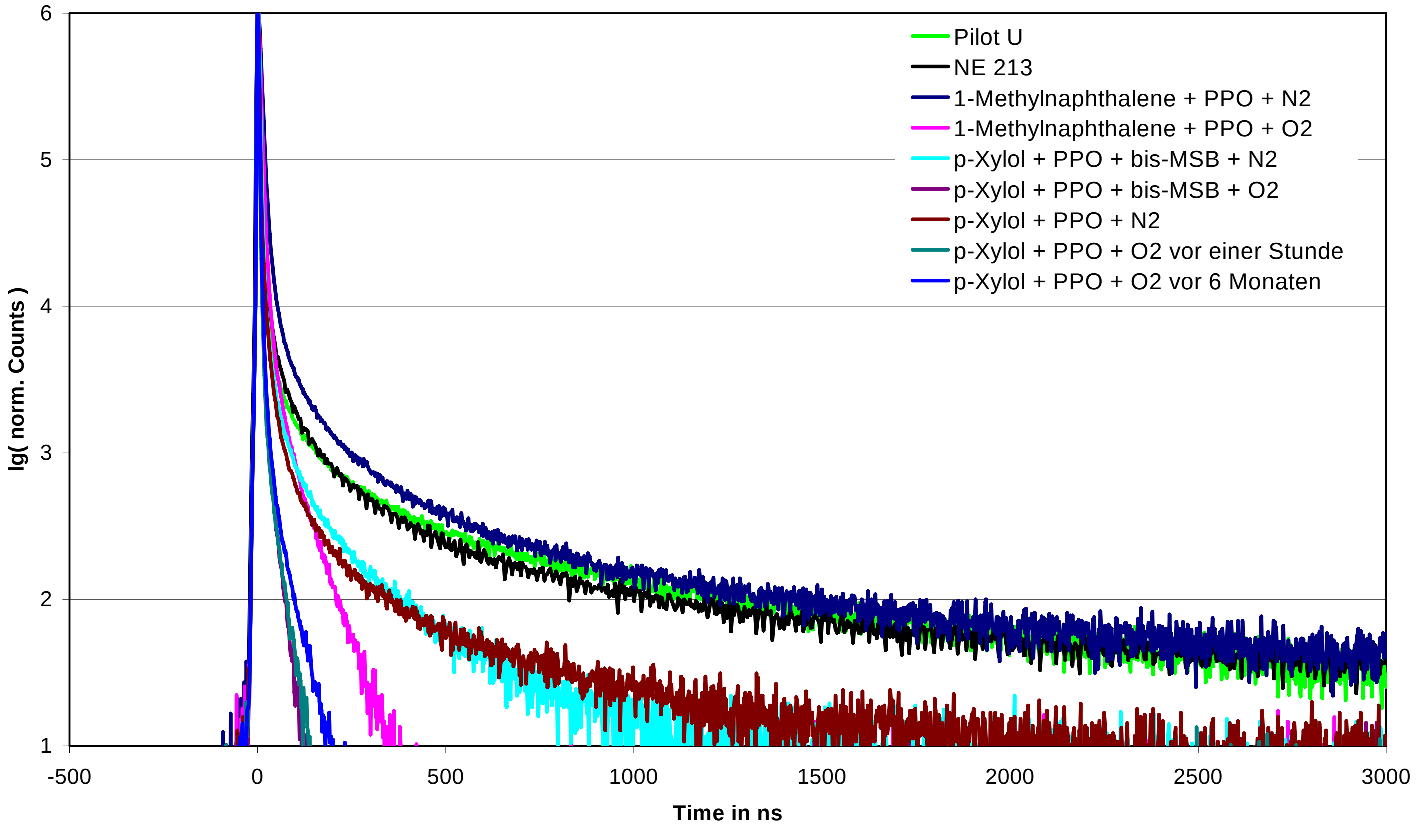


BV2562
(Proxitronic)





Low Afterglow Liquid Scintillators



Further Information see Poster:

Light Decay of Liquid Scintillators

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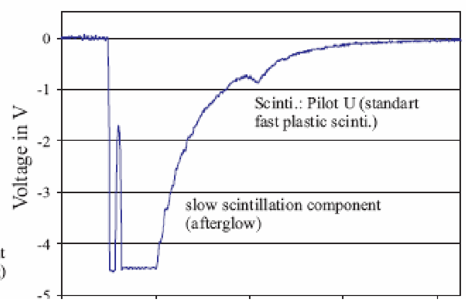
Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Motivation: Radiography with PW-Laser

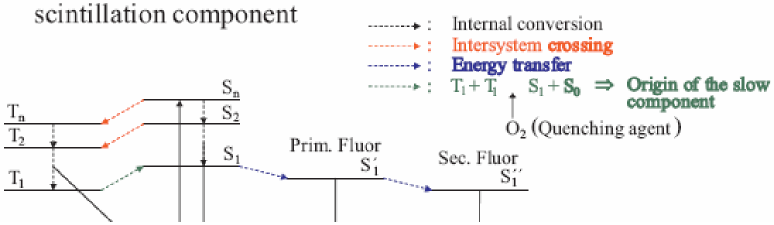
For the detection of neutrons and other particels from a plasma source of a high intensity laser we need a fast scintillator with negligible afterglow. Thus we can separate by time-of-flight faint neutron signals from the pulse of a very intensive -flash, which is also genereted in the laser plasma.

Scintillation light decay, measured by a photomultiplier tube, after a short (ps) and very intensive -flash from a laser plasma source:



Theoretical Background

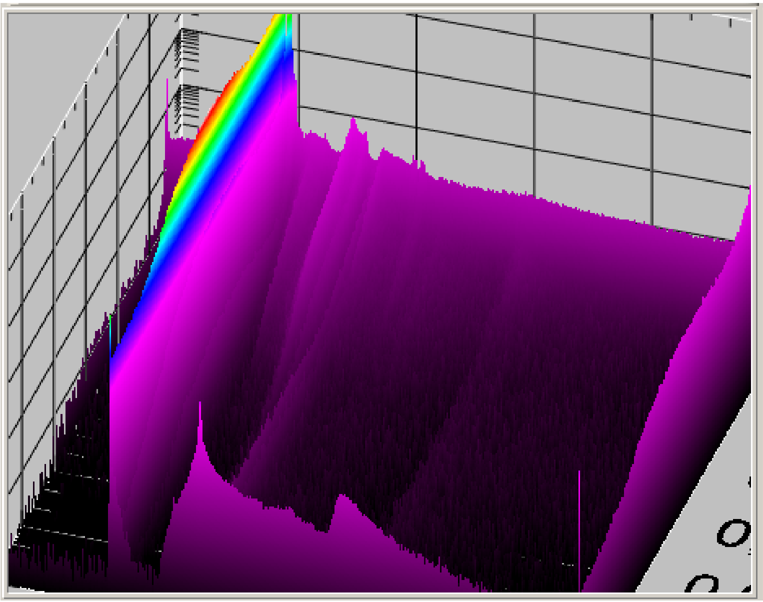
- Primary excitation of carbon -electrons in aromatic compounds
- Transfer of solvent excitation energy to the fluor
- The measured signal is determined by the fluorescence of the first excited state in the fluor
- Scintillations which originates from triplet-triplet interactions in solvent constitutes the delayed or slow scintillation component
- Oxygen as quenching agent reduces the influence of the slow scintillation component

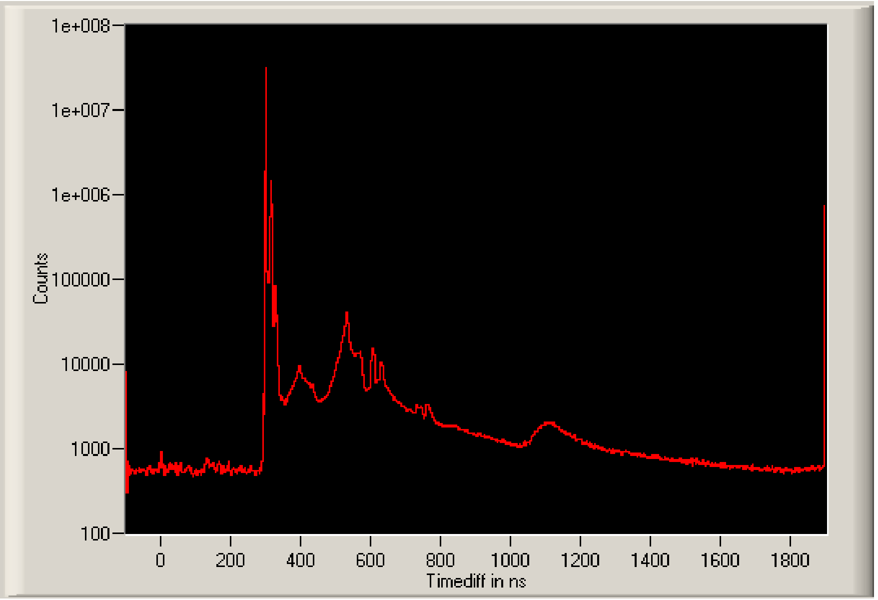


Thank You

PM-Response mit ps-Diodenlaser

ohne Filter





MCP-Response mit ps-Diodenlaser

ohne Filter
Schwelle: 18 mV