Decay Spectroscopy at GSI and FAIR – III Applications

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GSI Darmstadt, Germany

presented at

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Goa, India,

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How applications are born

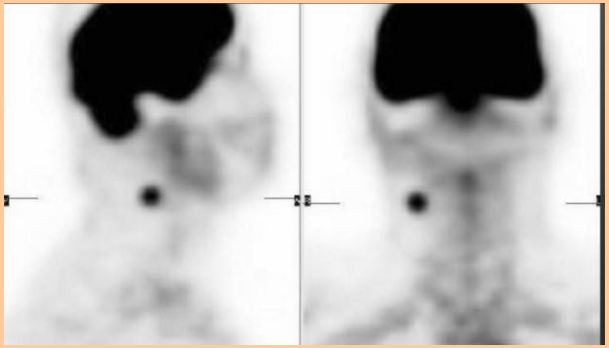
Triviality: γ-detector arrays have in inherent position sensitivity for activities close to the detector elements

detector

source

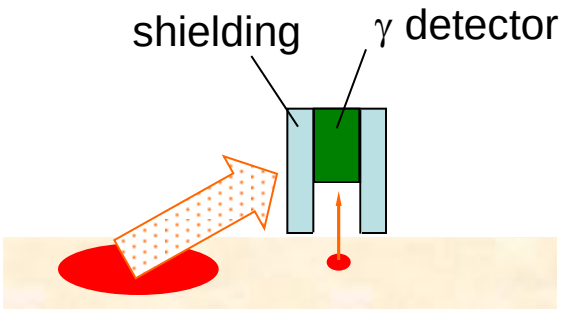
Medicine: Cancer diagnosis and therapy

Tracers with radioactive isotopes are used to mark tumours

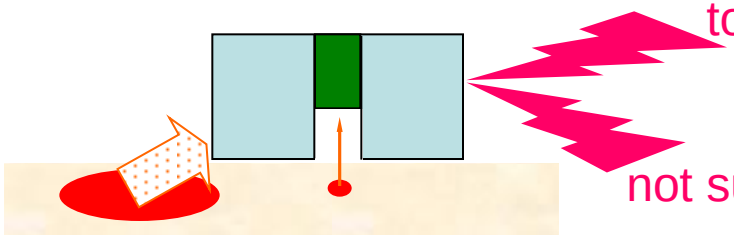


γ-probes are used to localize these tumours

... useful tools for radio-guided surgery



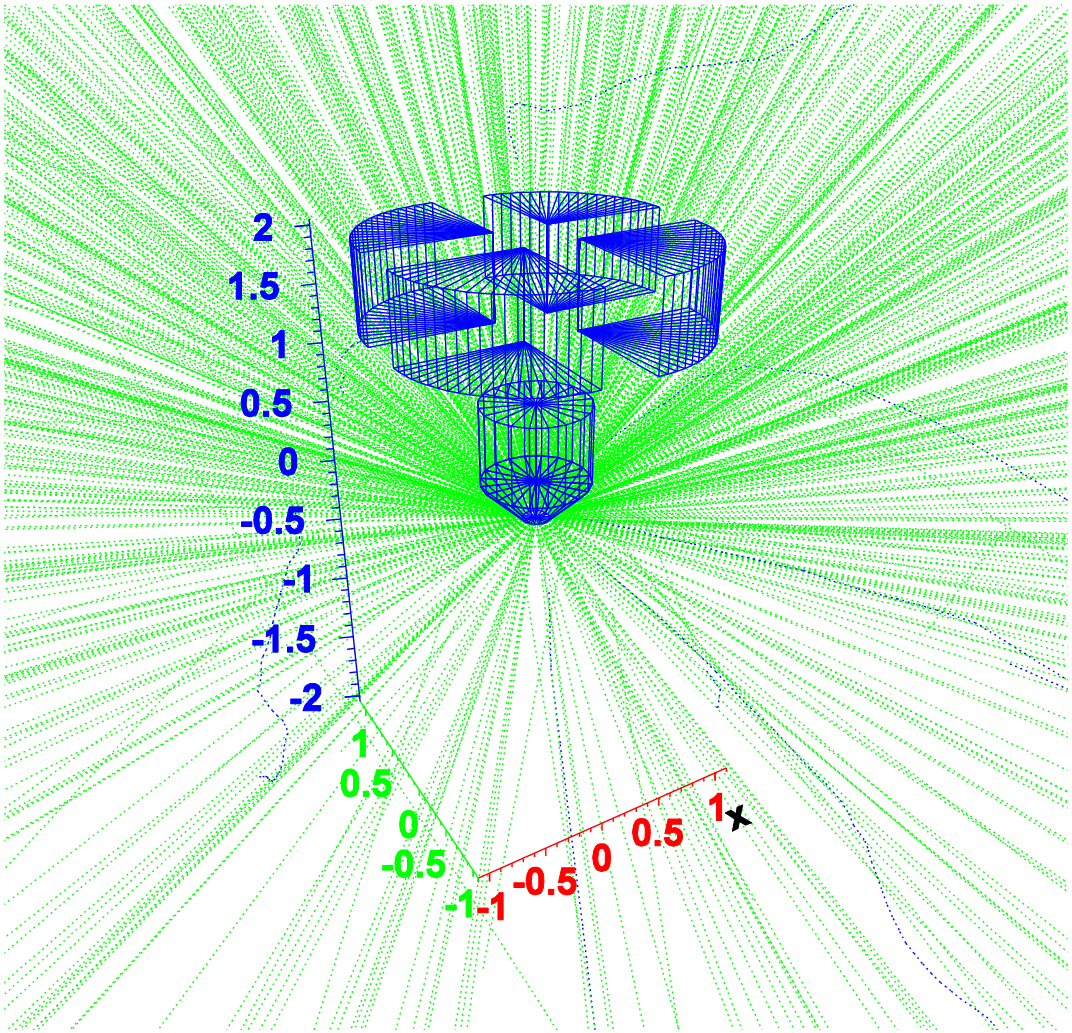
low energy tracer (100-300 keV)



high energy tracer (> 300 keV)

PET imaging, e.g. with ^{19}F[FDG]

Detector array for PET tracers

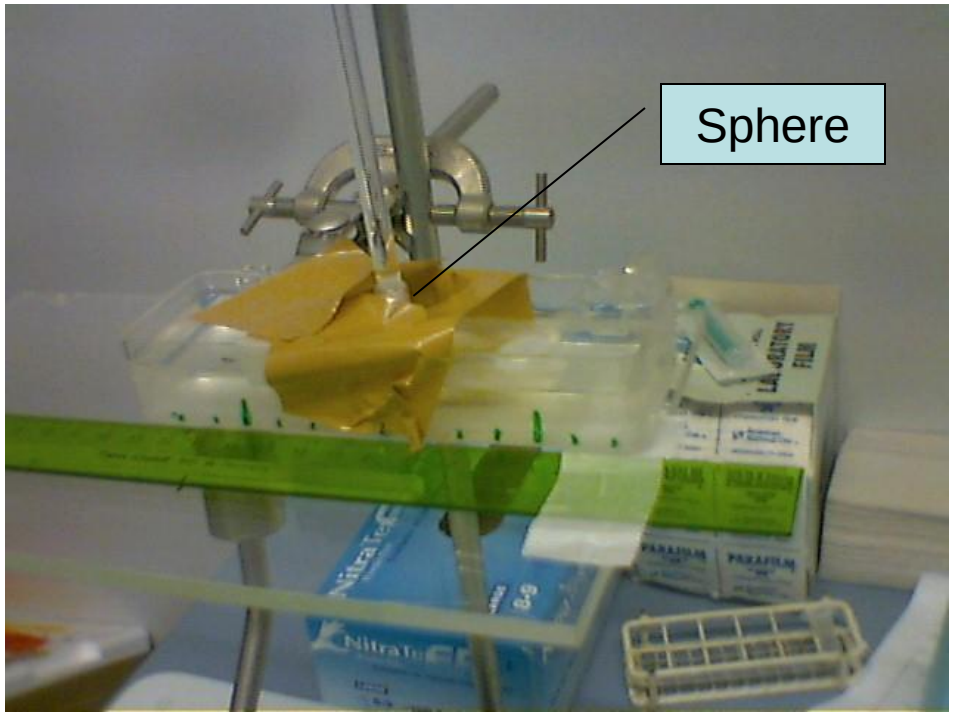


Radiation enhancement determined from count rate distribution

No collimator needed

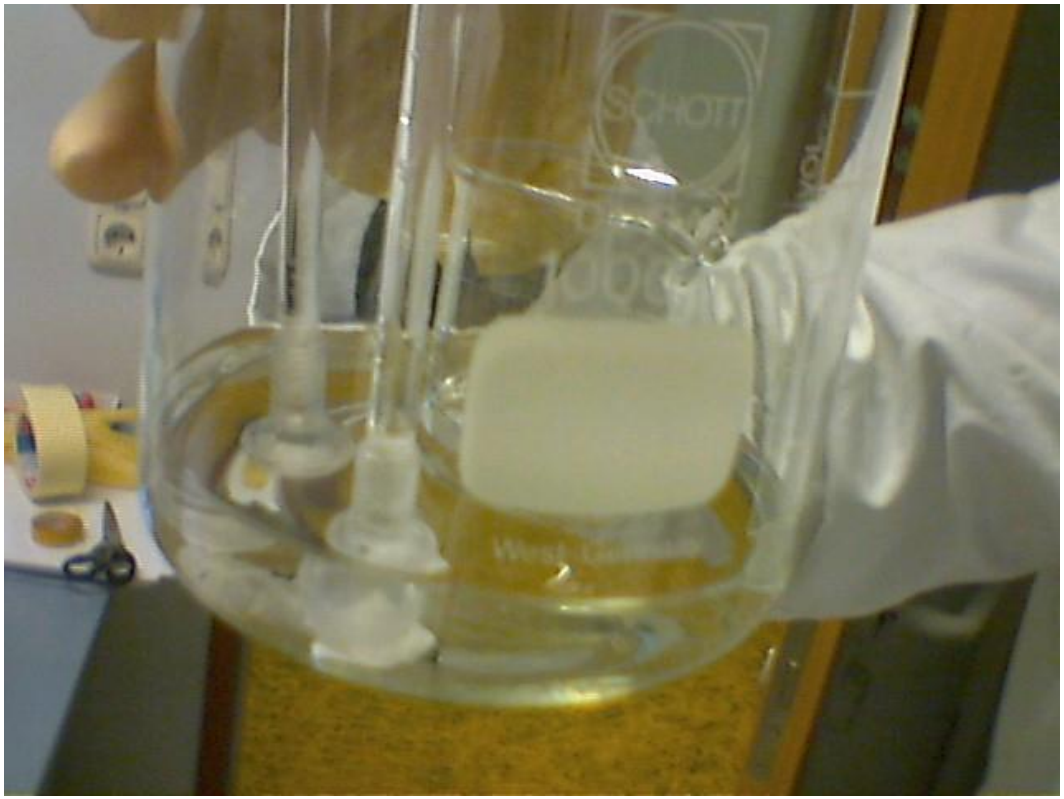
3D sensitivity

PhantomMeasurements



^{19}F[FDG] in water bassin (background) and enriched in 1cm plastic sphere (target)

Phantom-Measurements

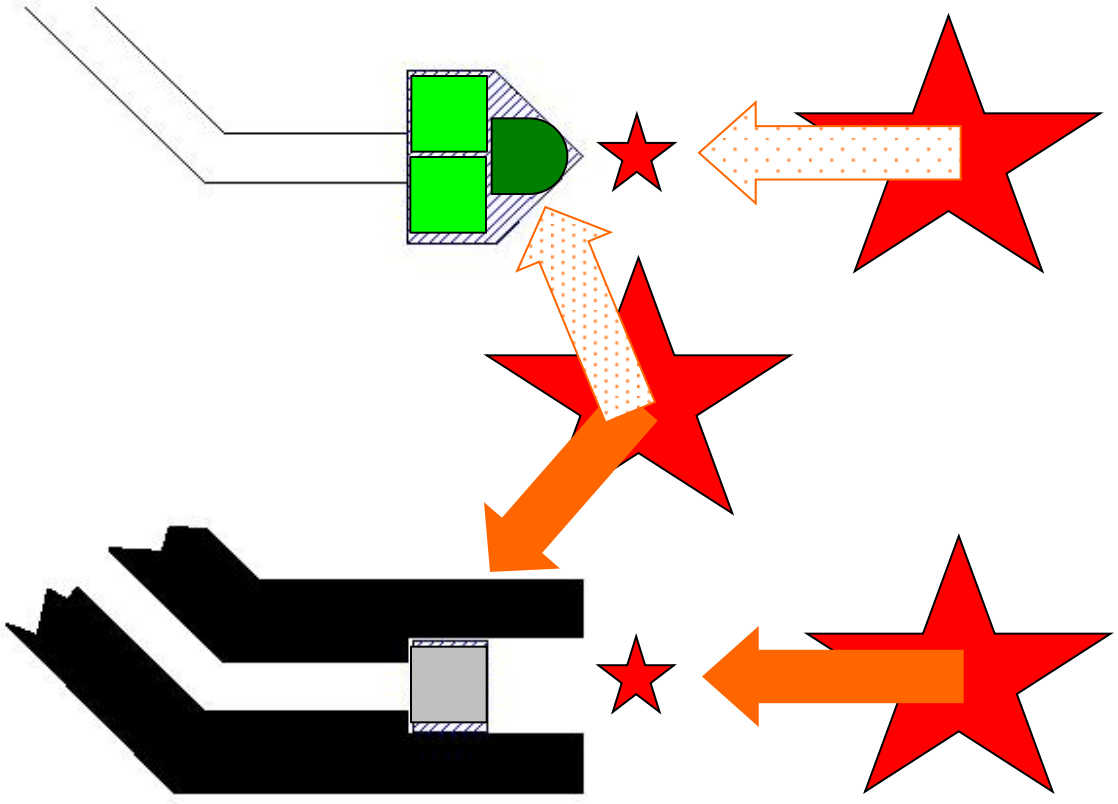


multiple target investigation

γ probe with 511 keV PET tracer

newly developed

electronically collimated probe



conventionally shielded probe

ε_{PET}: up to 7 cps/kBq

background suppression:
- lateral: perfect
- backward: perfect
- distant: ≈ 10% conv. probe

pos. resolution: ≈ 9 mm

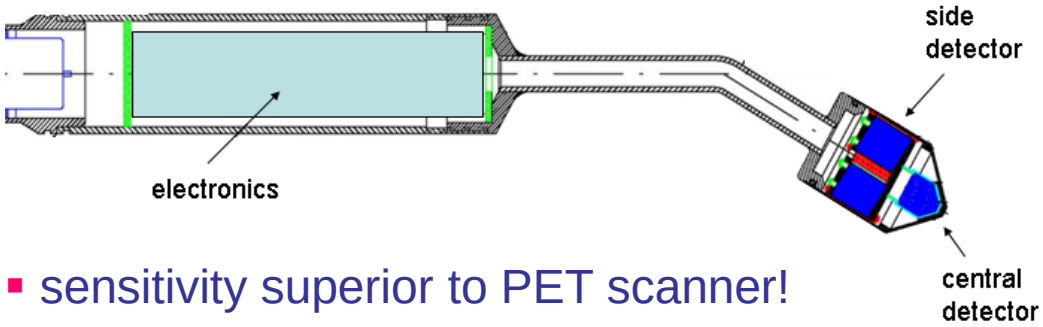
ε_{PET}: < 1 cps/kBq

background suppression:
- lateral: inadequate
- backward: inadequate
- distant: $I = I_0 (r_0 / r_1)^2$

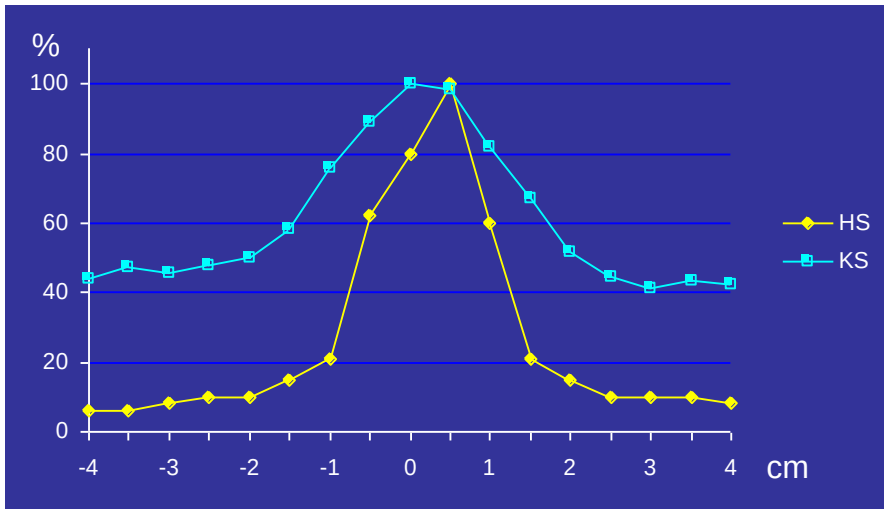
pos. resolution: > 15 mm

Medicine: Cancer diagnosis and therapy

γ - locator: High energy PET probe



- sensitivity superior to PET scanner!
- excellent background suppression
- unsurpassed position resolution



Clinical applications (so far):

head, neck, spine, liver, thyroids, bones, pancreas, thorax, abdomen...

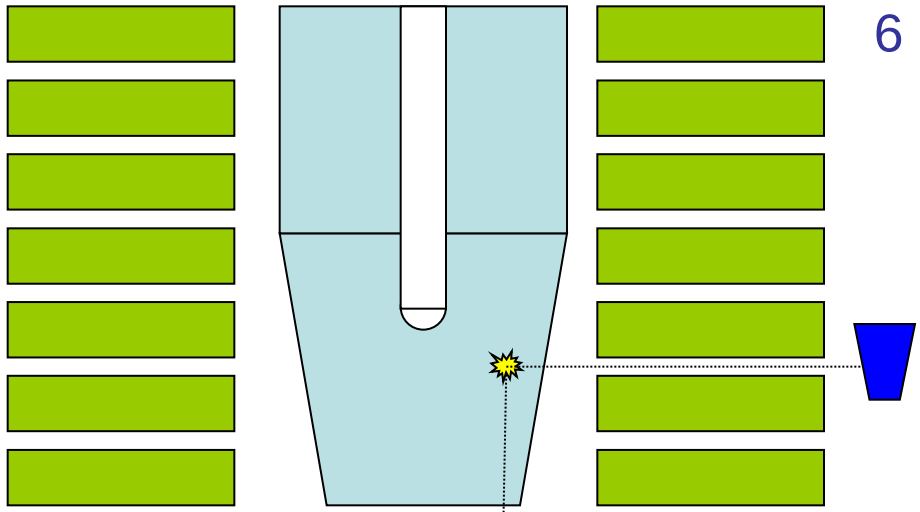
Useful tool for surgeons:

higly sensitive, selective, fast...

How applications are born

Spin-off: γ-scanner principles has myriads of obvious applications

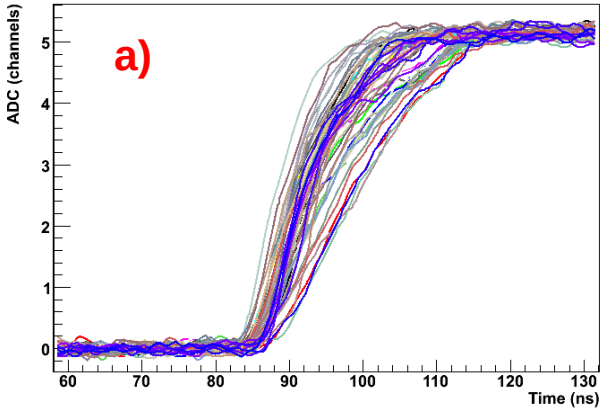
Conventional 3D Scanner

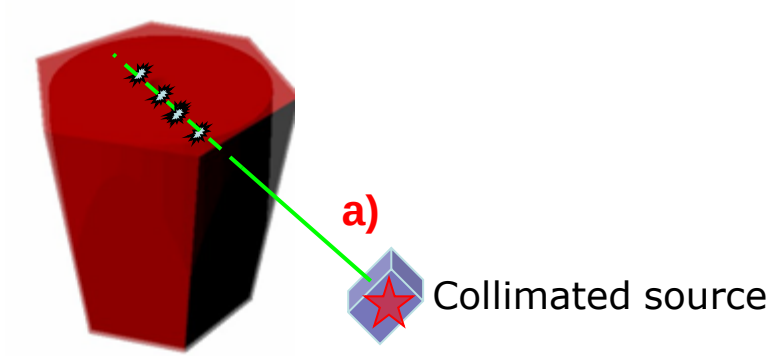


- 2 month scanning time for 1 sector
- inaccurate back side characterization

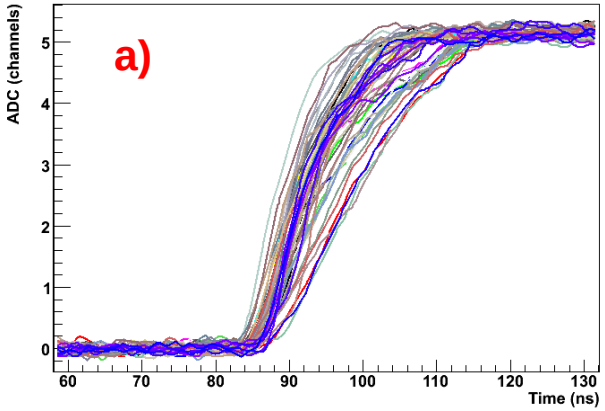
1GBq ^{137}Cs source

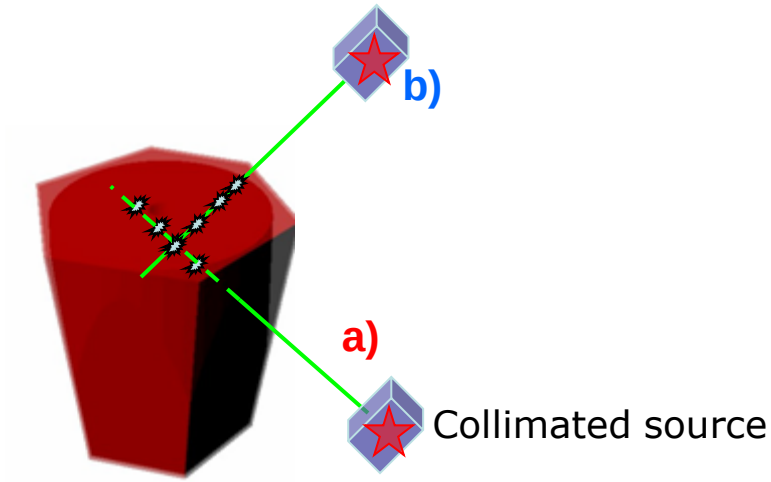
Scanner based on pulse shape comparison scan



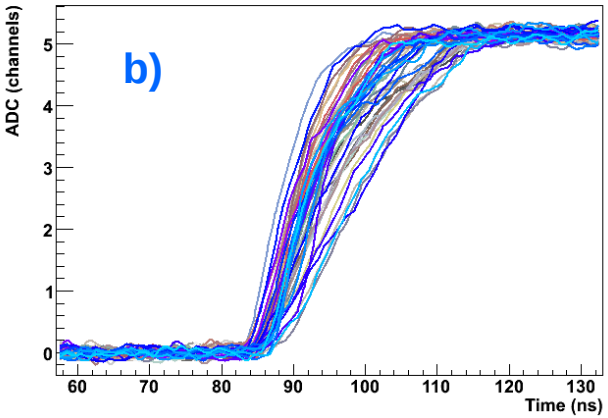


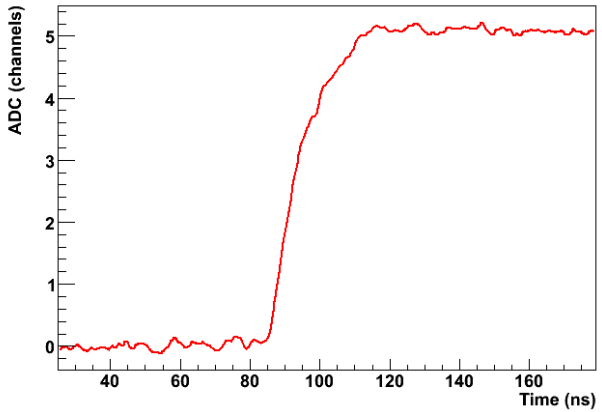
Scanner based on pulse shape comparison scan





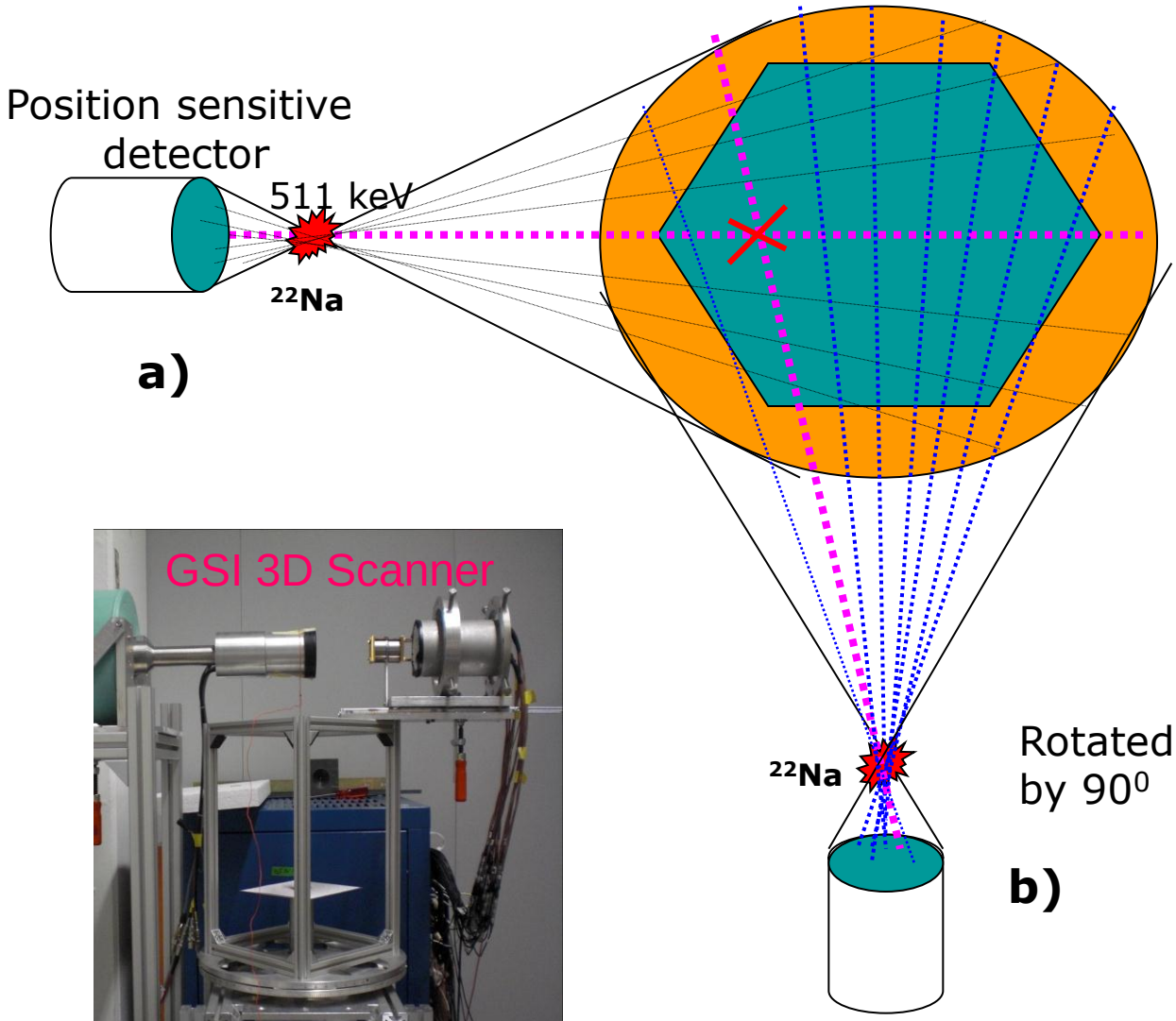
Geometric crossing point: **x,y,z**





Common pulse out of data sets (a) & (b)

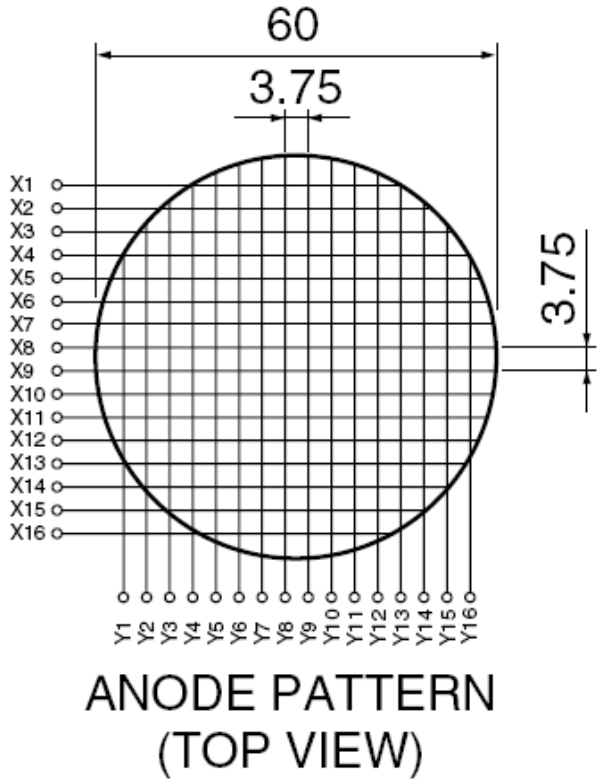
Pulse shape comparison scan method based on a position sensitive detector



- Recording pulse shapes for positions (a) and (b)
- Identical signals at the crossing point.

Gamma Camera: Individual multi-anode readout

16 wires in X axis and 16 wires in Y axis



ANODE PATTERN
(TOP VIEW)

LYSO scintillator

d = 76 mm

t = 3 mm

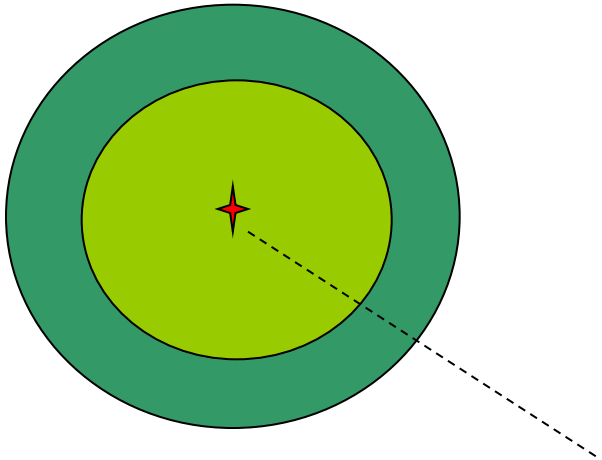
ρ= 7.4g/cm^3

Hamamatsu R2486 PSPMT

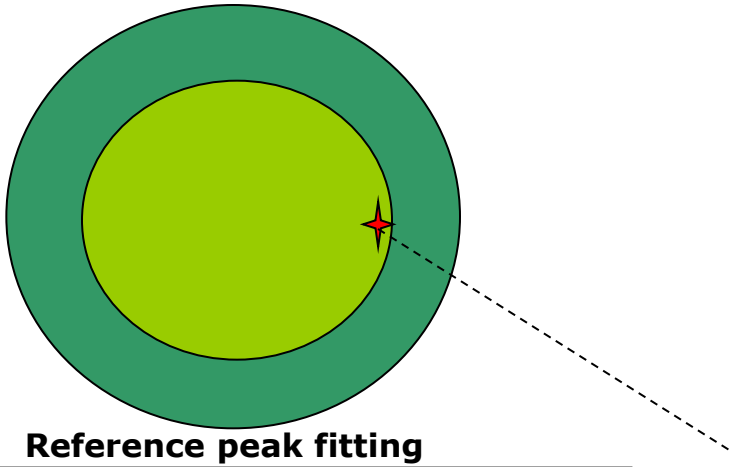
Photocathode = 56.25 mm

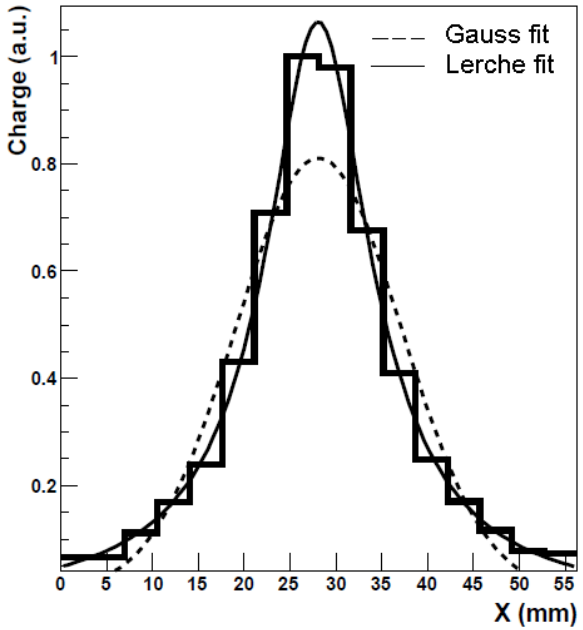
Position Reconstruction

Central Interaction

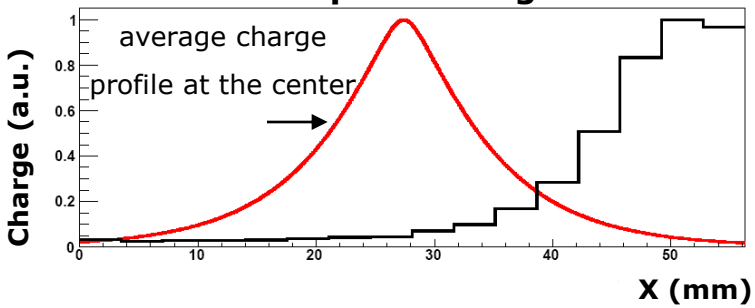


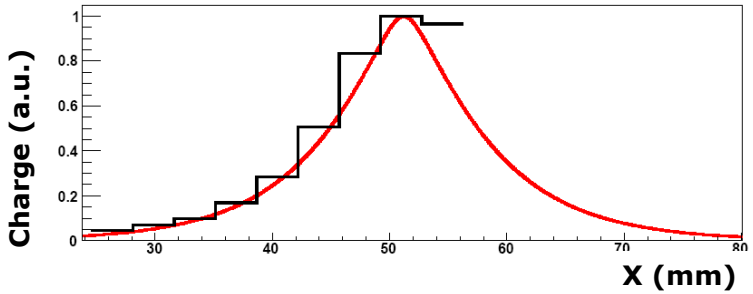
Peripheral Interaction





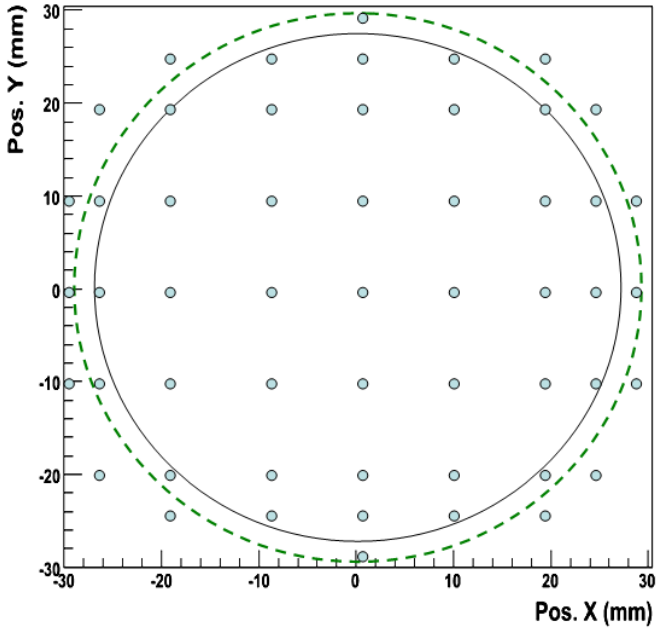
Reference peak fitting



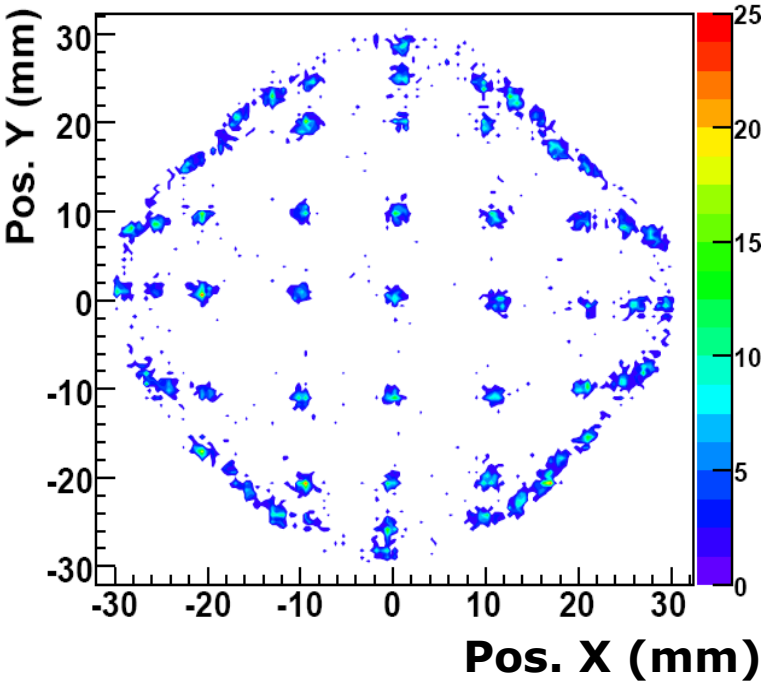


Position reconstruction

Collimated Na-22 source placed at different positions



Reference peak fitting

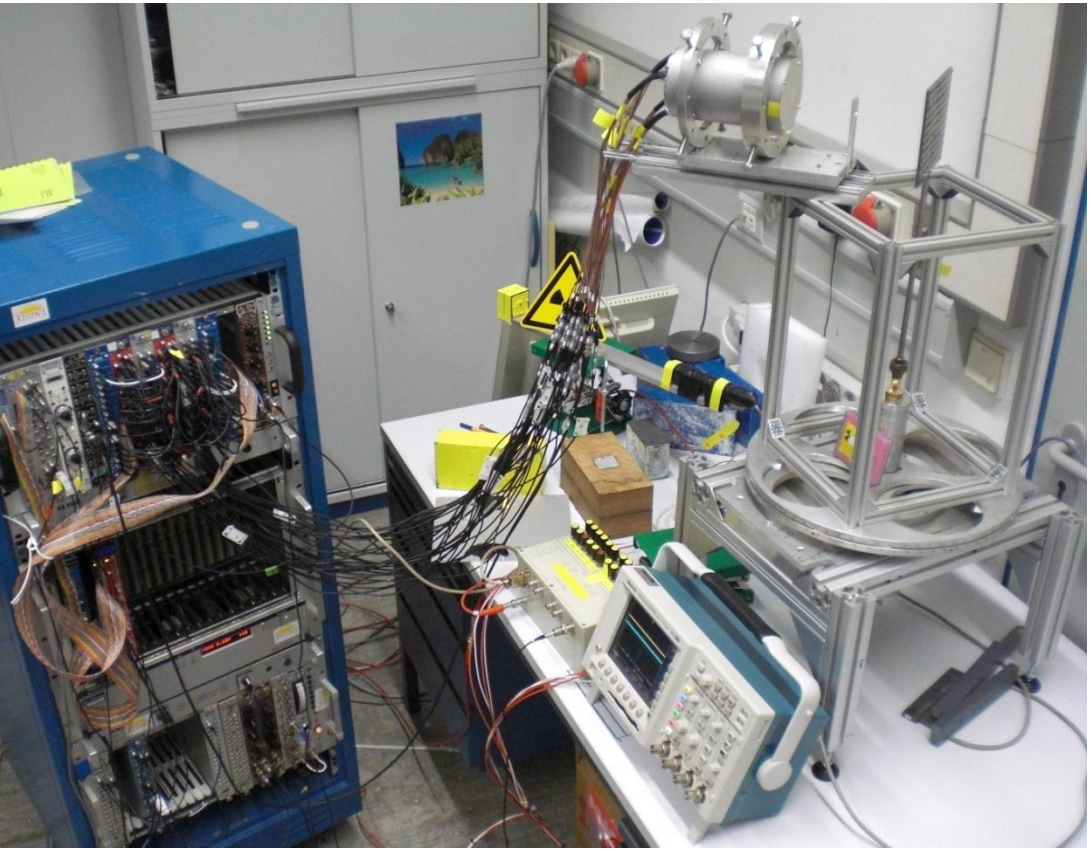


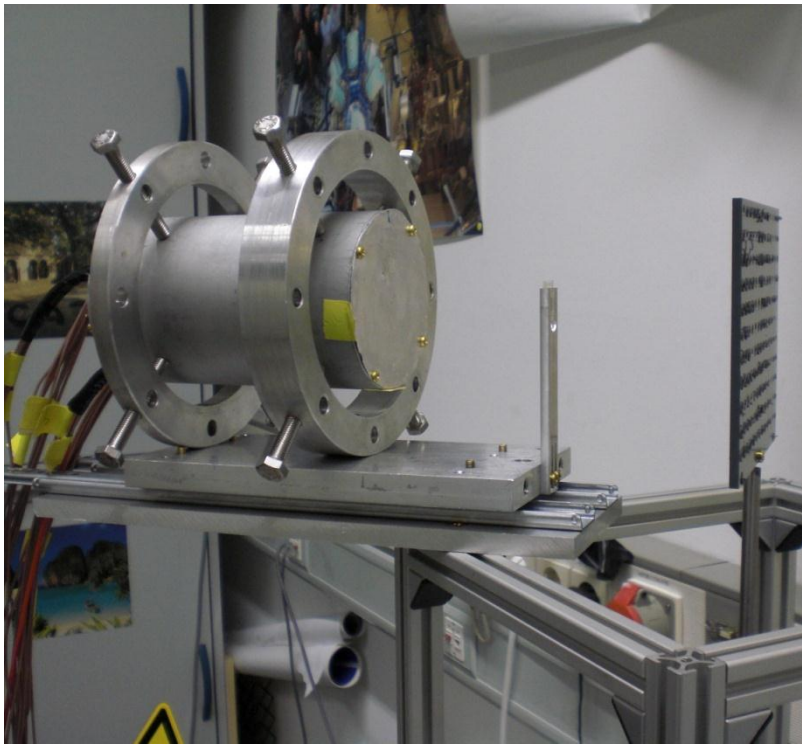
Linear for 50 mm

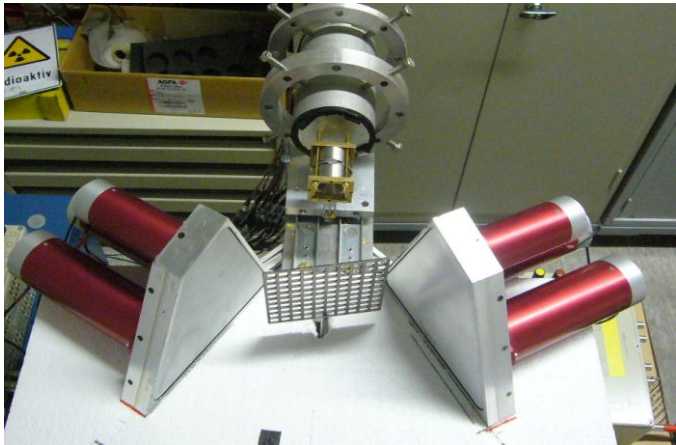
Field of view = 28 cm^2

Average spatial resolution in X and Y < 1 mm (FWHM)

3D Scanner set-up

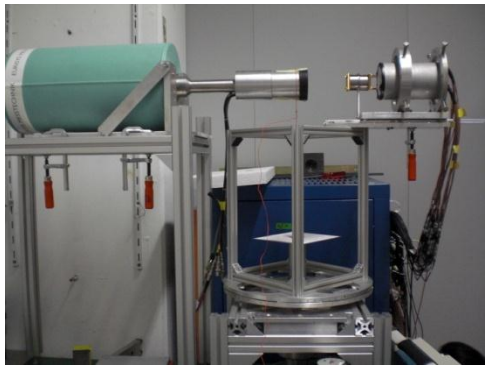


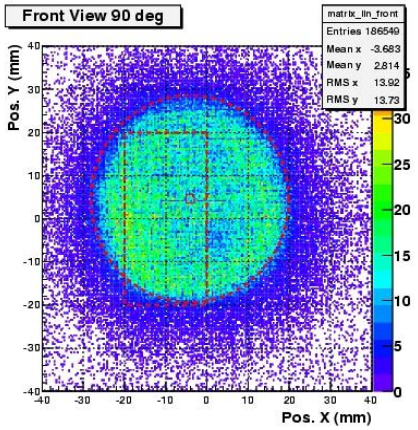




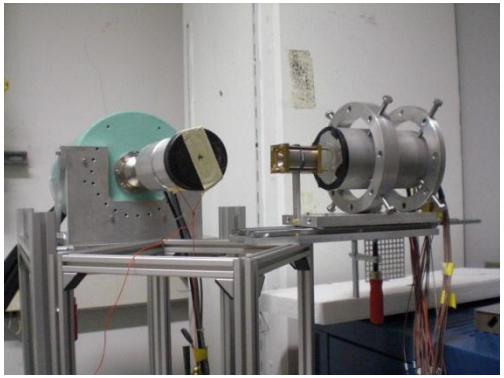
Detector Scan

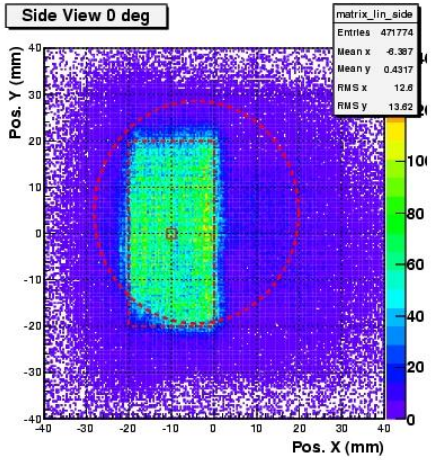
Front view (0 deg):



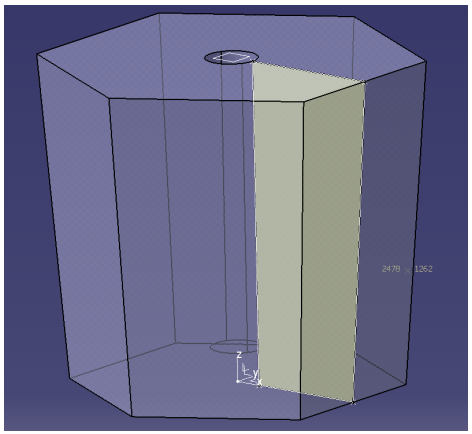


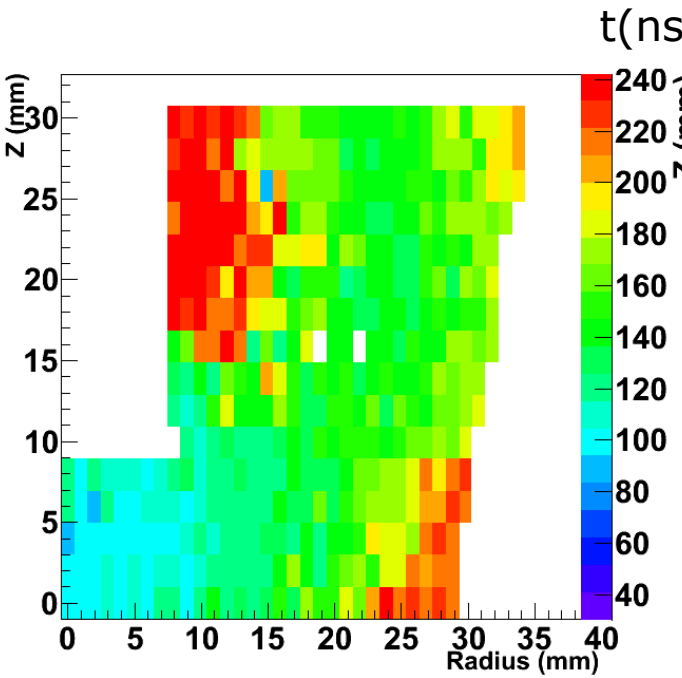
Side view (90 deg):



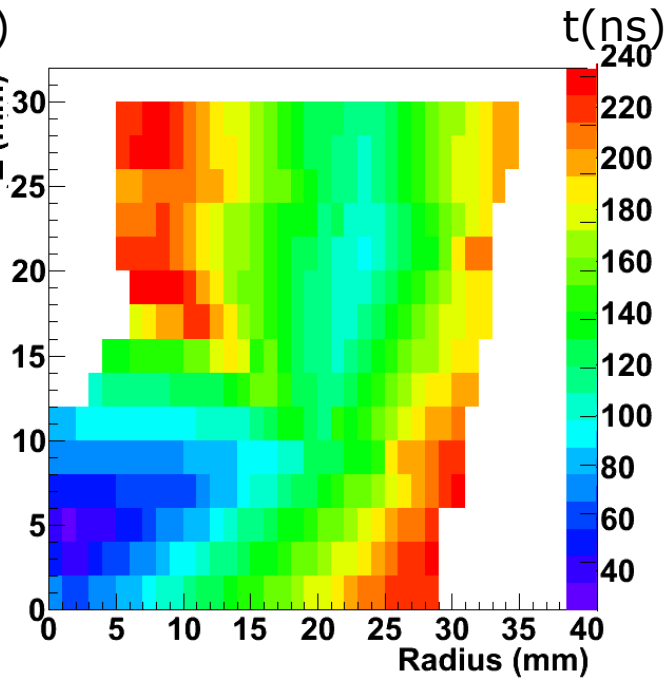


From 2D to 3D: First deep insight into the detector





Experimental

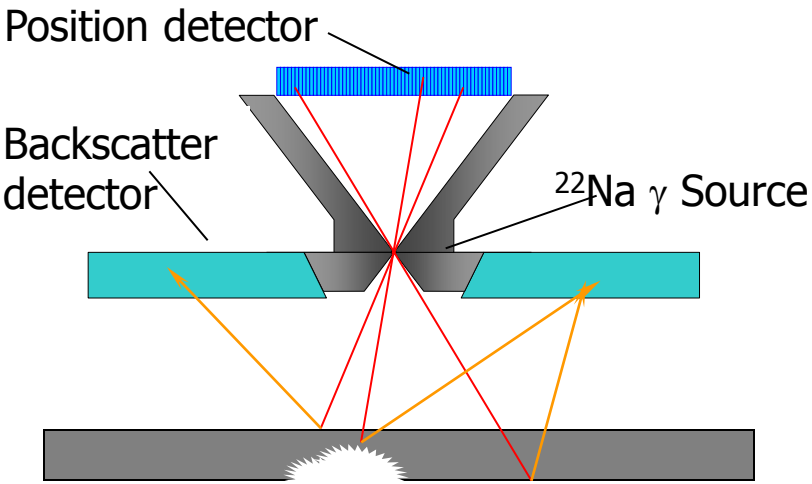


Simulated

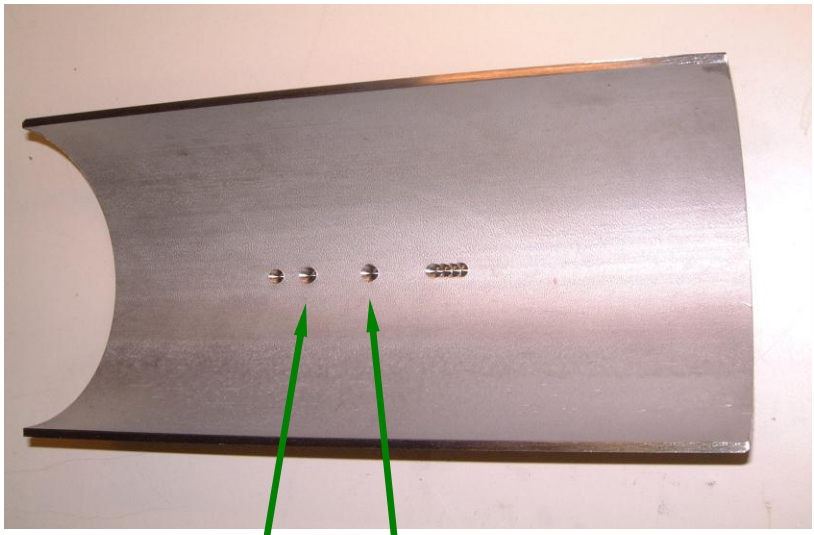
Discrepancy in the risetime values near the core in ring 1 ~ 50 ns

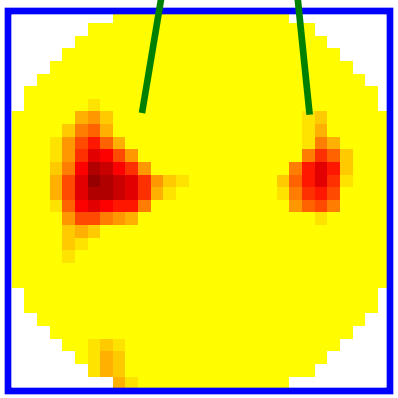
Extremely important to have an experimental pulse shape basis for PSA to be applied to the complicated geometries.

Industry: Corrosion control for pipelines



internal corrosion





γ-backscatter imaging

to detect hidden

pin-hole corrosion, depositions, obstructions...

Detection of Land Mines

10^8 Land mines layed worldwide!

10^6 additional one‘s per year!

Only 10^5 mines are cleared per year!

1 accident per 2000 cleared mines!

1 Mio. people died since 1975!

300.000 children are disabled!

Task: Find the mine!!!

Required detection efficiency:

100% down to critical depth!

99.6% down to any depth!

ATM

Size: ∅ = 15…30 cm, d = 6…10 cm

Depth: D = 0…30 cm

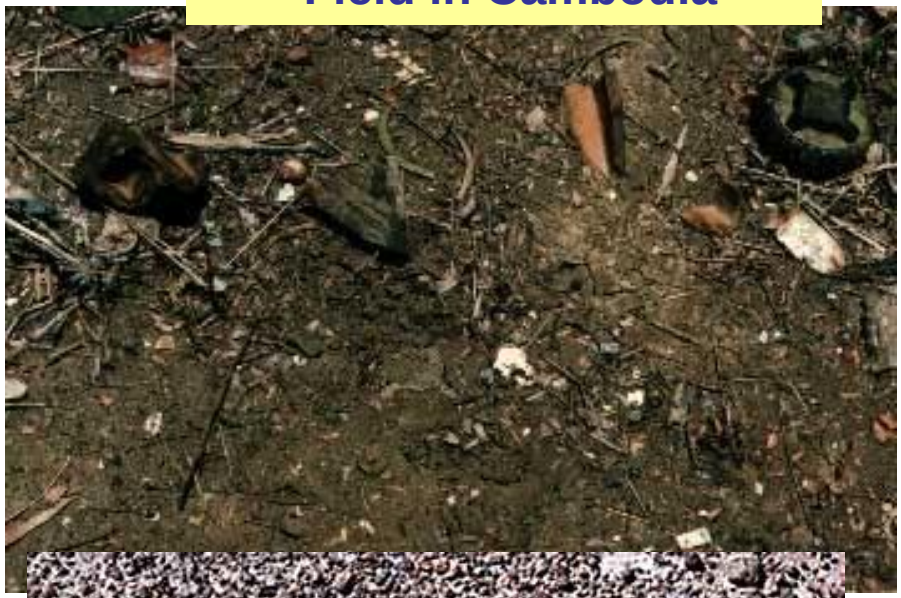
APM

Size: ∅ = 8…12 cm, d = 4…6 cm

Depth: D = 0…10 cm

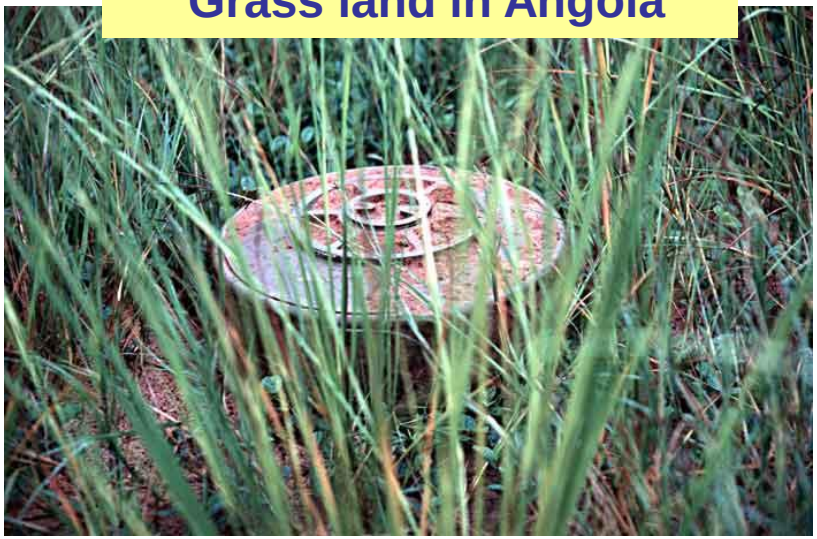
Mines can be everywhere

Field in Cambodia



Gravel in Angola

Grass land in Angola



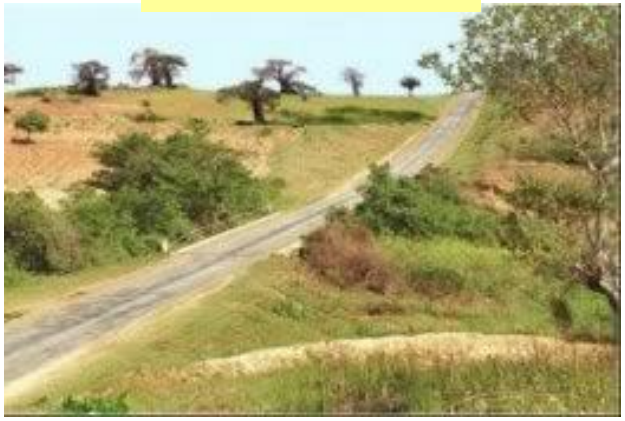
Field in Cambodia

Mines can be everywhere

Balkan

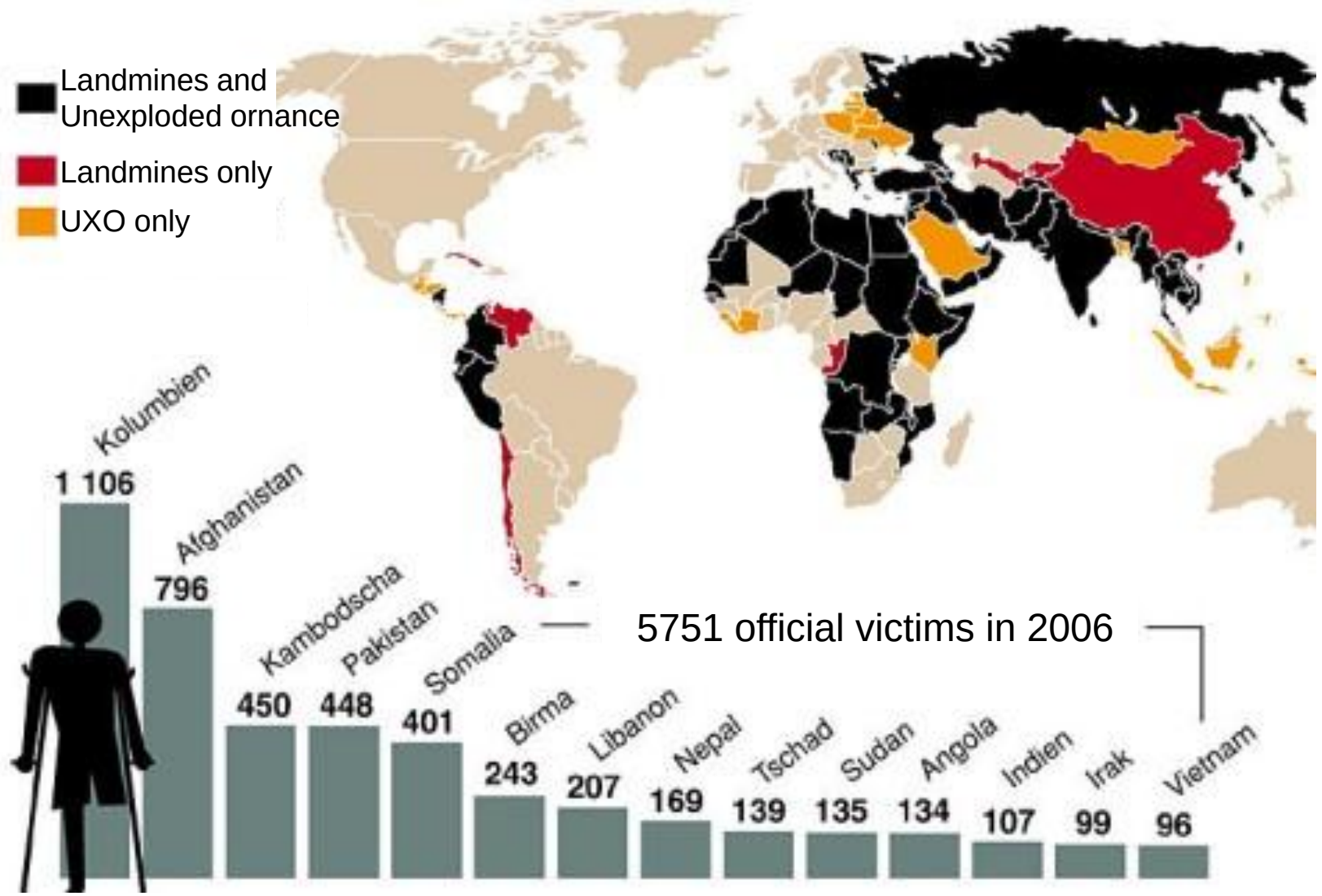
Afghanistan

Sri Lanka



Namibia

Many countries are affected



Mines are inhuman…

Every 22 minutes somebody is injured or killed by a land mine!!!

Searching and preparing for de-mining

Metal detector false alarm rate: 1000/1

Mine prodding in practice

An APM costs 3$

To remove it costs 300$ to 1000$

A de-miner can clear 2 m^2 of land per day

Vegetation cutting machines

Expensive

Mine blasts may damage it

Repair parts to be imported

Leaves a mess for de-miners

Ruins forests

Vegetation cutting machines

Remotely controlled flail

Expensive

Mine blast destroys it

Armoured flail

Expensive

Can detonate mines

Ground penetrating machines

Tiller

Destroyed by found mine!

Machines clear only to 90-95%

Mines can be relocated

Roller

Destroyed by mine not found!

Biological mine search

African Giant Pouched Rats

Searches up to 200m^2/day

20 min to discover a mine

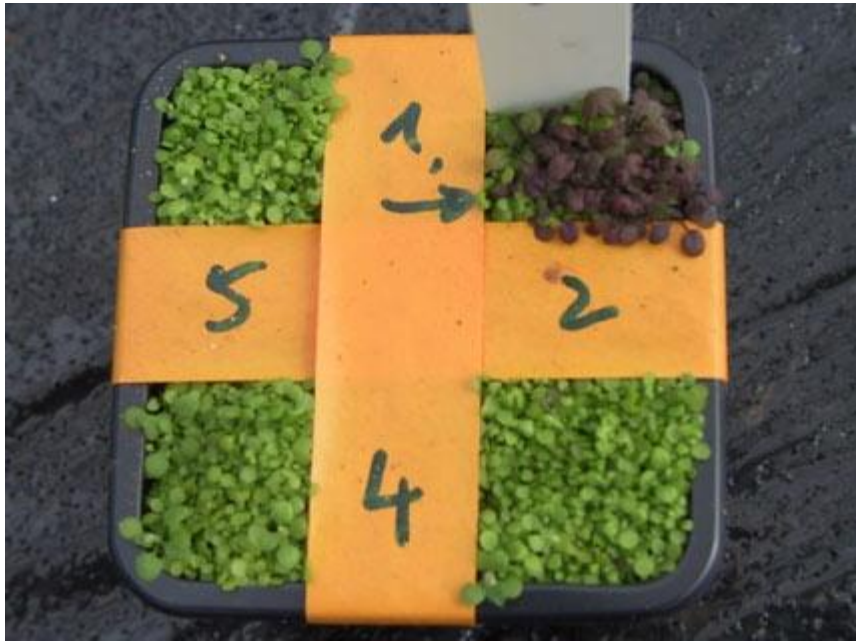
Verification by 2. rat or other means

Rat weighs < 1.5 kg

Mine odour vanishs after 1-2 years

Biological mine search

Thale cress (Arabidopsis thaliana) changes color in presence of a mine within 4-6 weeks of growing!



Needs to be sown…

Requires humid soil…

Effect seizes with old mines

Conclusion on mine detection techniques

Main detection techniques:

– Metal detector

– Search needles

No other technique is really estabished!

Strongly varying environmental conditions:

- ground (soil, swamp, sand, gravel, rock…)
- vegetation (none, grass, shrubs, forest, roots…)
- landscape (plain, trench, hill, canyon, mountain…)
- climate (tropical, moderate, cold, wet, dry…)
- population (rural, settlement, city, dense, weak…)

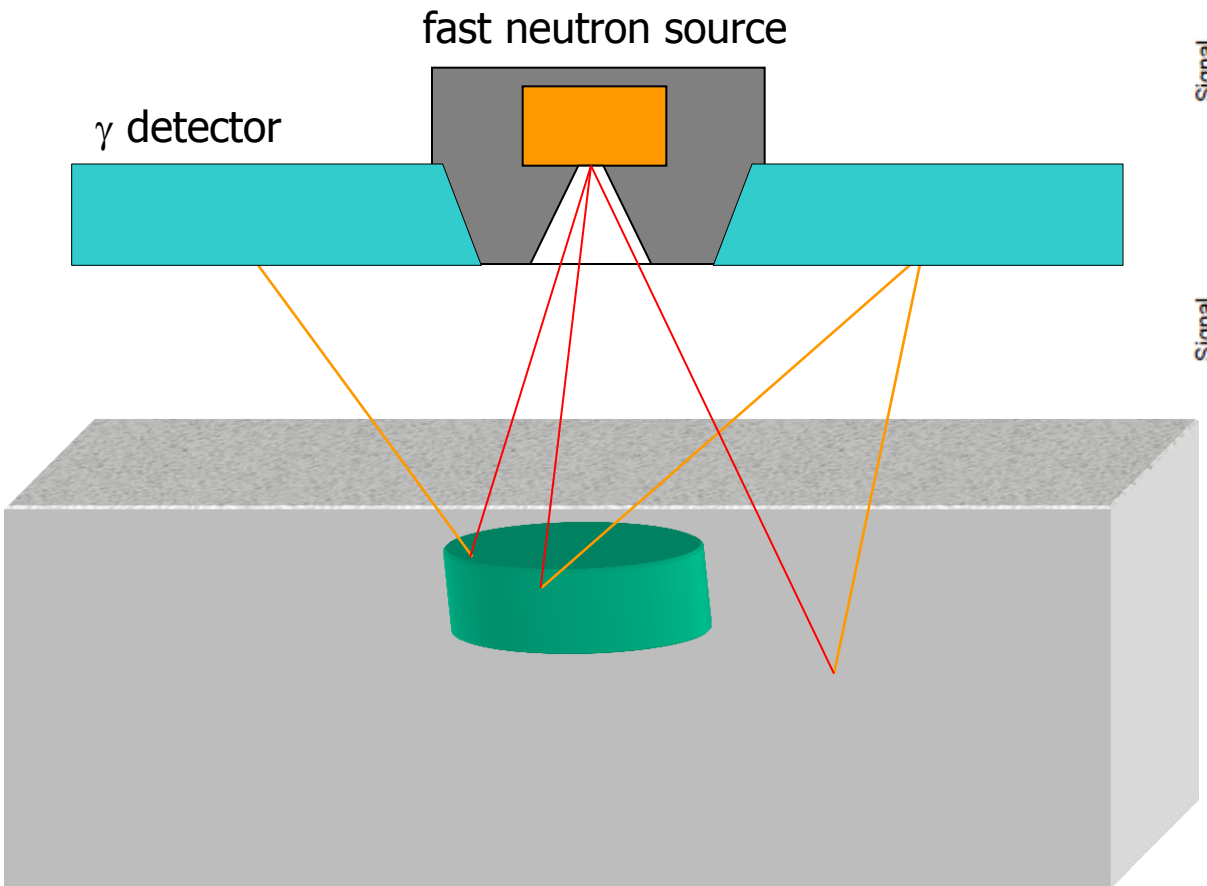
Variety of techniques
Affordable techniques
Combination of techniques

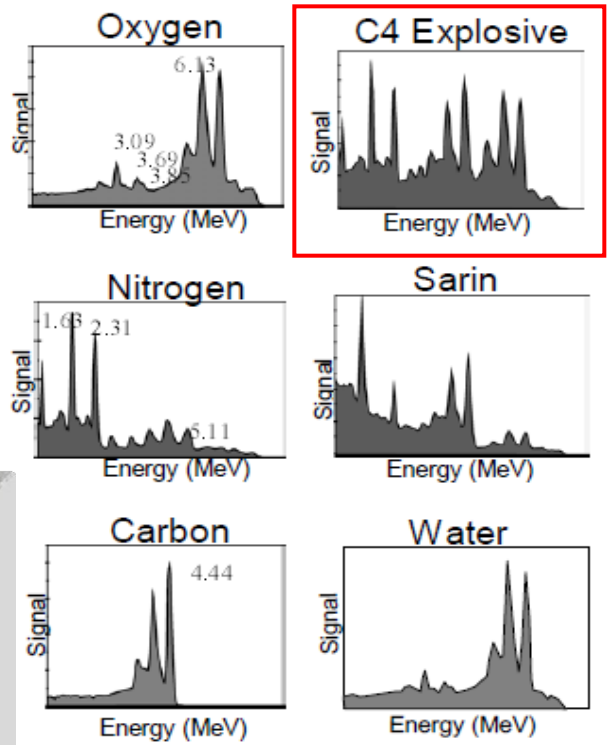
→ Nuclear techniques may add

Mine detection with Fast Neutron Activation

FNA: potentially high selectivity → fingerprint γ spectrum

high background radiation → low sensitivity

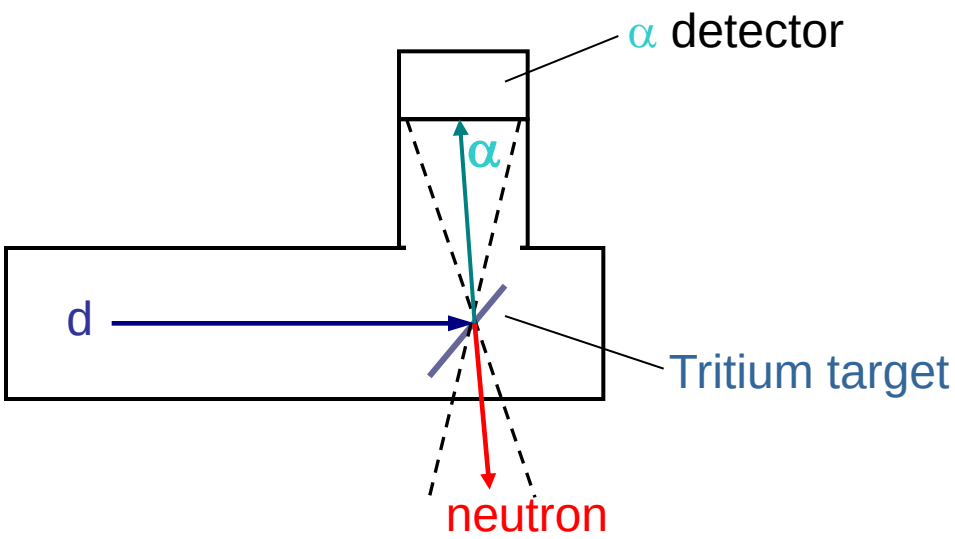




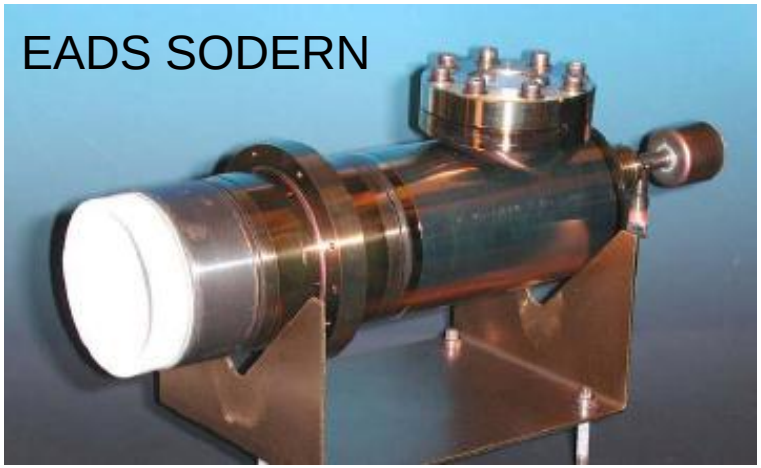
FNA background reduction

Background reduction by n - γ coincidence method

100 keV d + t $\rightarrow$ α + n



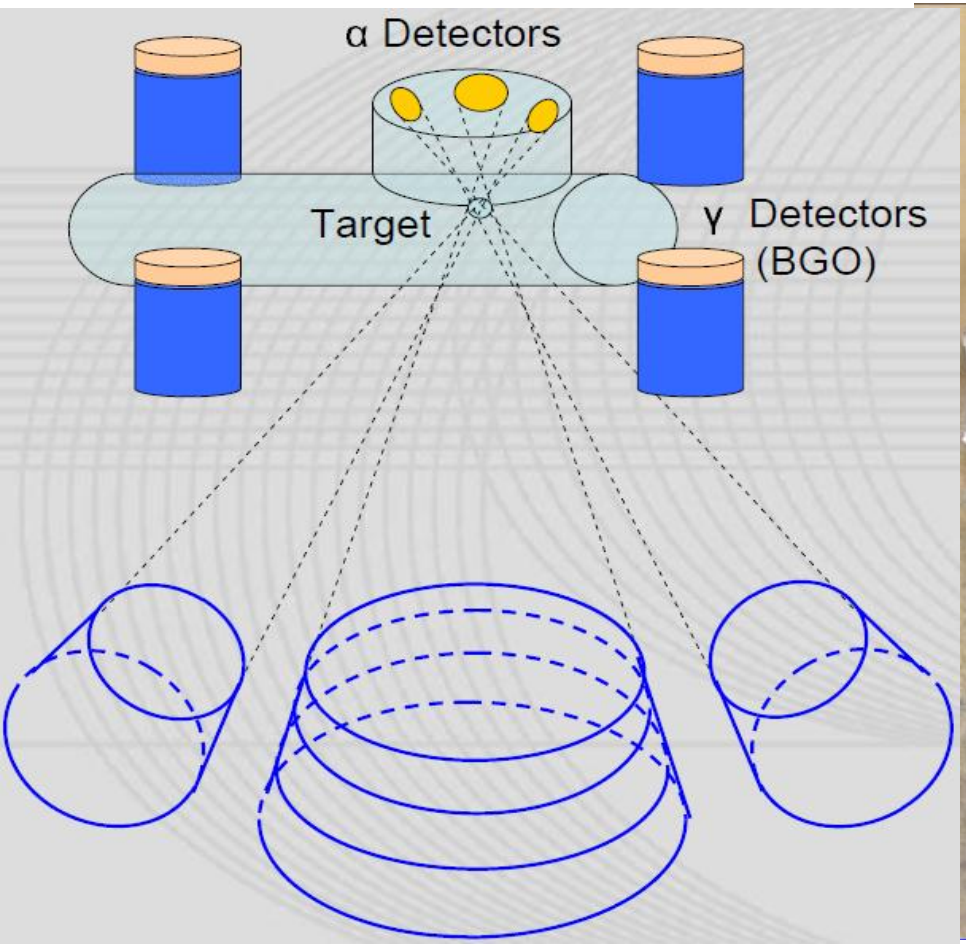
Neutron generator

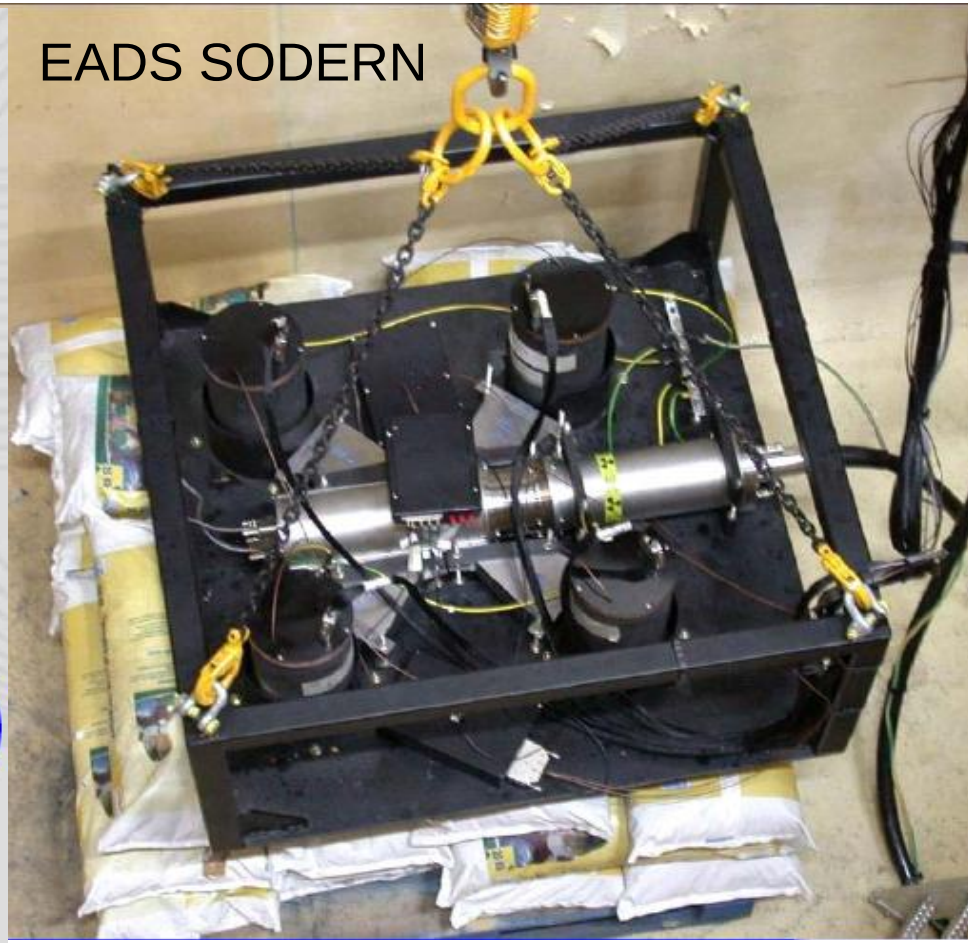


Multi detector FNA demonstrator

1 kW n-generator (10^8 n/s)
3 fast α detectors (10^6 α/s)
4 large BGO γ detectors ($3 \cdot 10^5$ γ/s)

Distinct activation areas
Improved efficiency

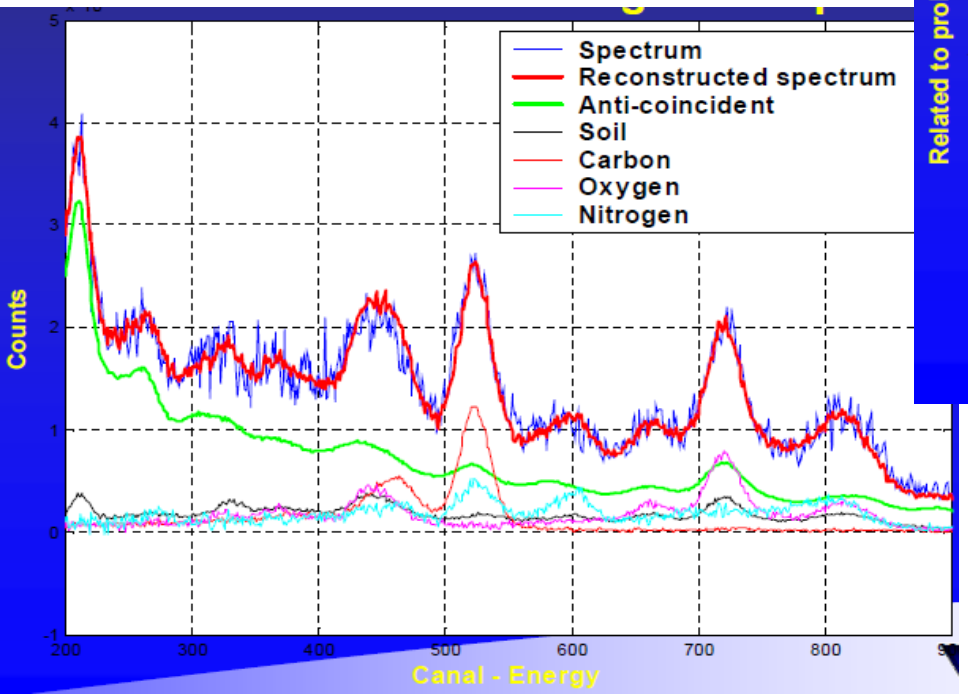




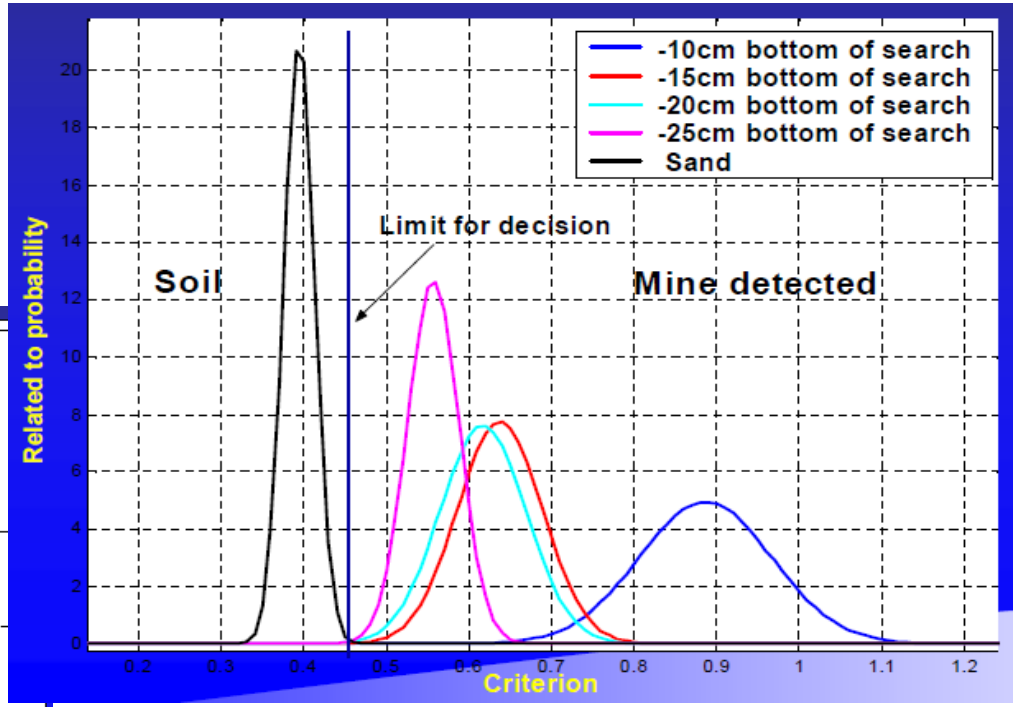
Demonstrator test results

Standard explosive in wet sand between 0 and 15 cm coverage

Deconvolution of a mine spectrum

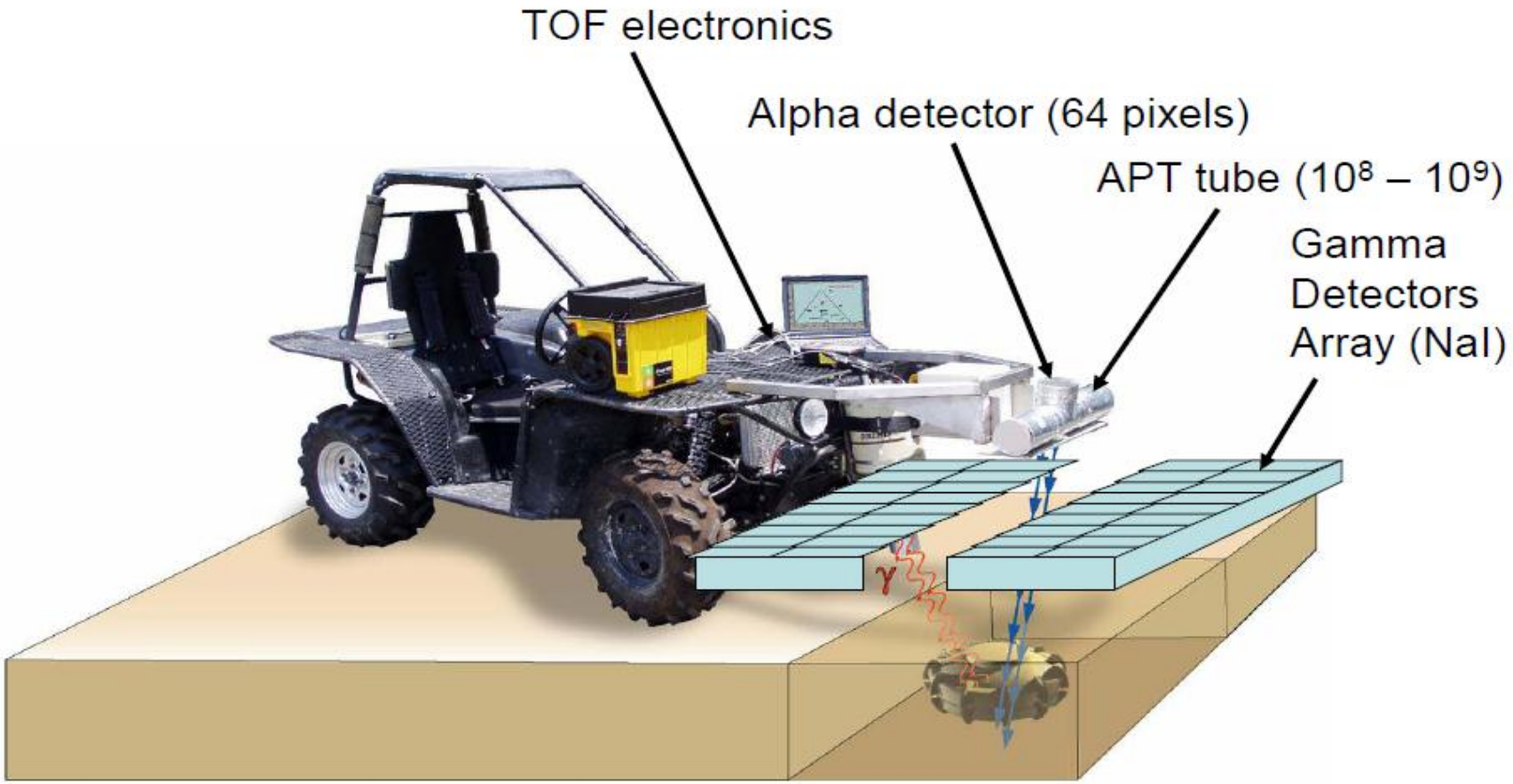


Limit for decision



2.3kg explosives
Flux : $2{,}5.10^7$ n/s
1 detector
5 minutes acquisition

A mine detection dream…

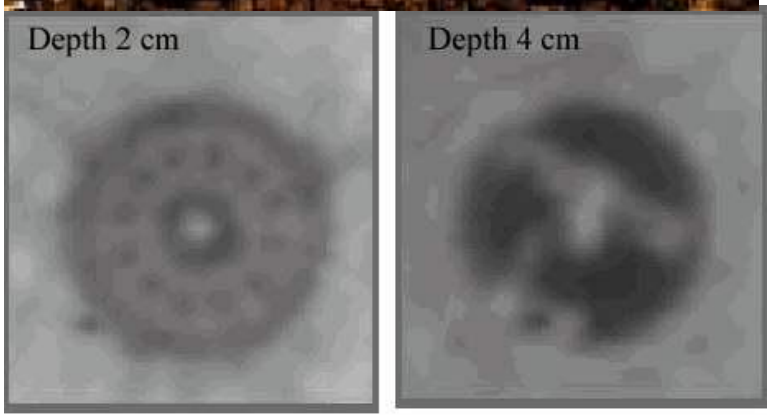


→ Vehicle required

→ Only ATMs detectable

An alternative: High power X-ray Imaging

APM: PPM2, 12cm ∅

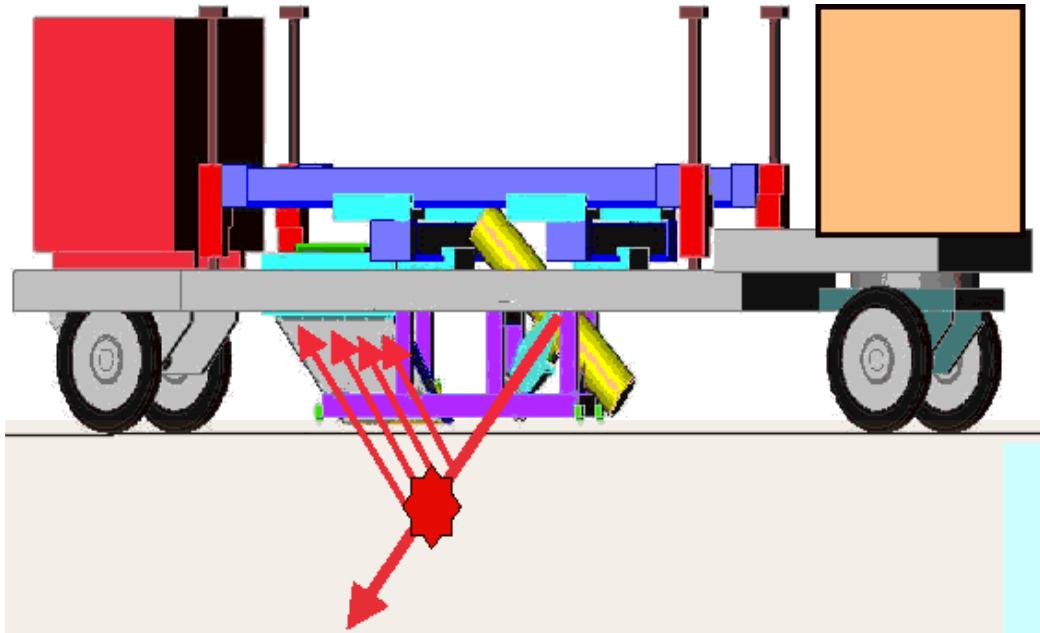


ComScan 450

YXLON, Hamburg

450 kV high flux x-ray tube

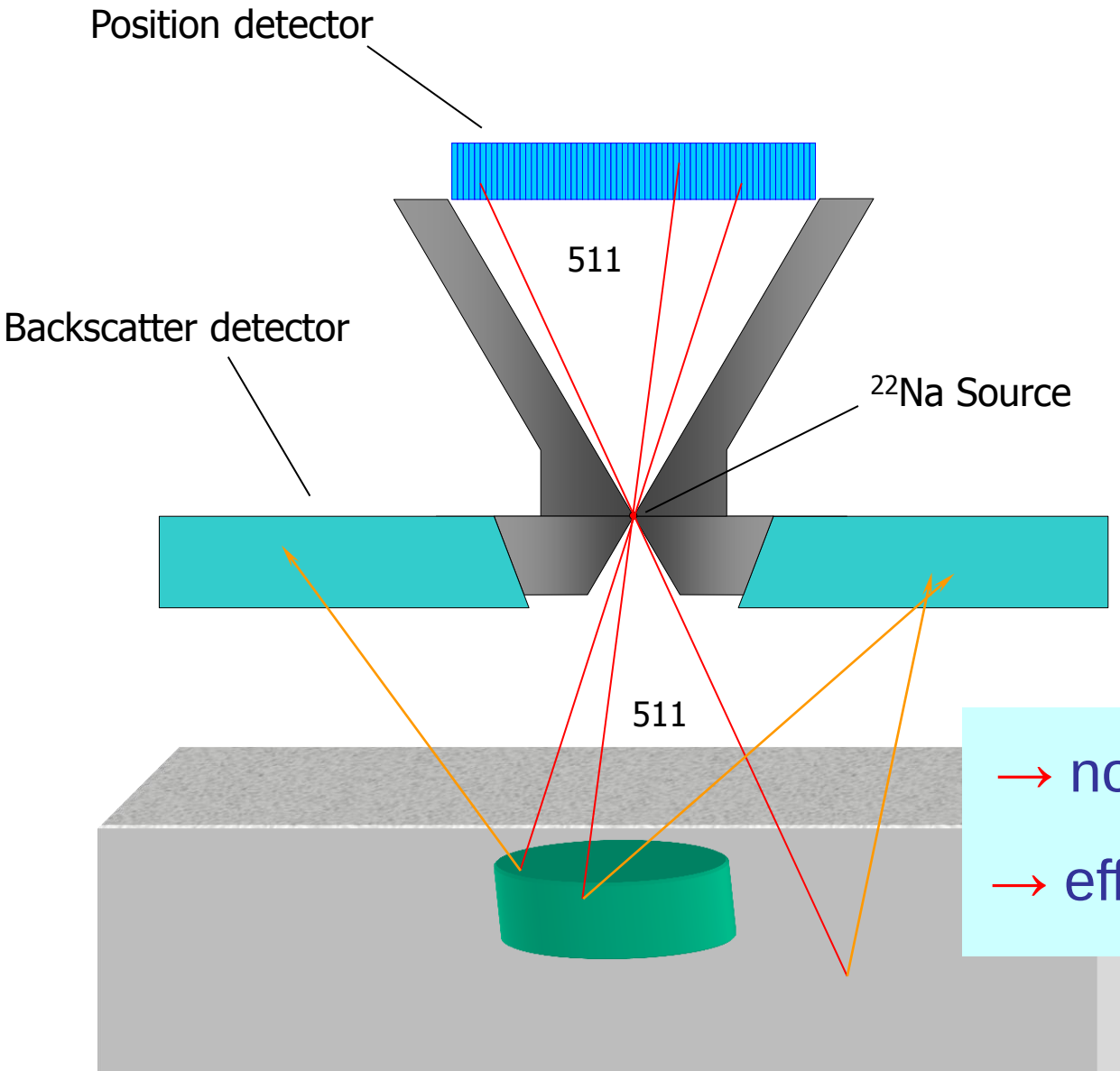
pixelated x-ray detector



→ Heavy power generator

→ Truck required

Backscatter Imaging with Positron Annihilation Radiation



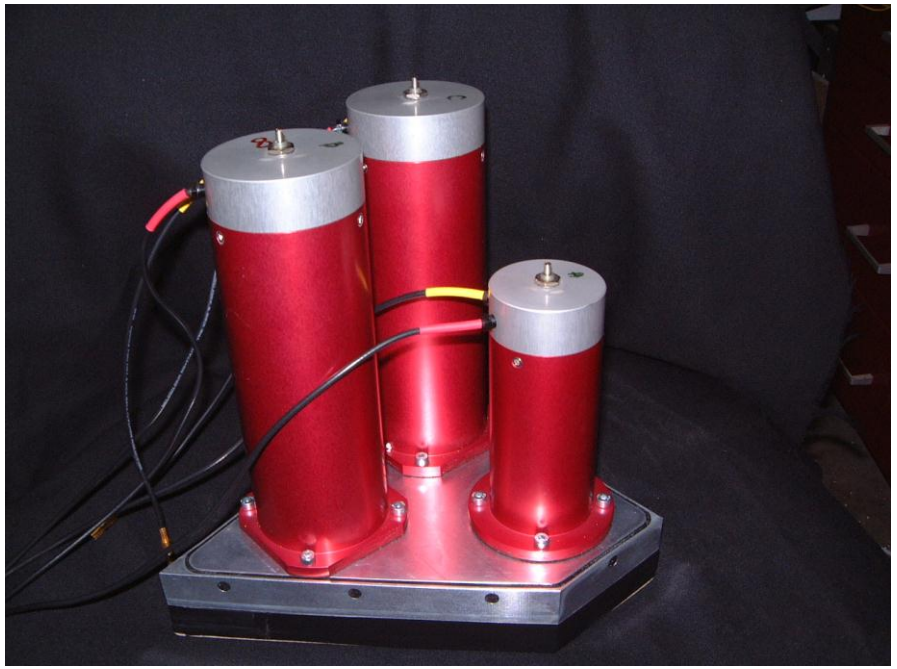
→ no BS-collimator

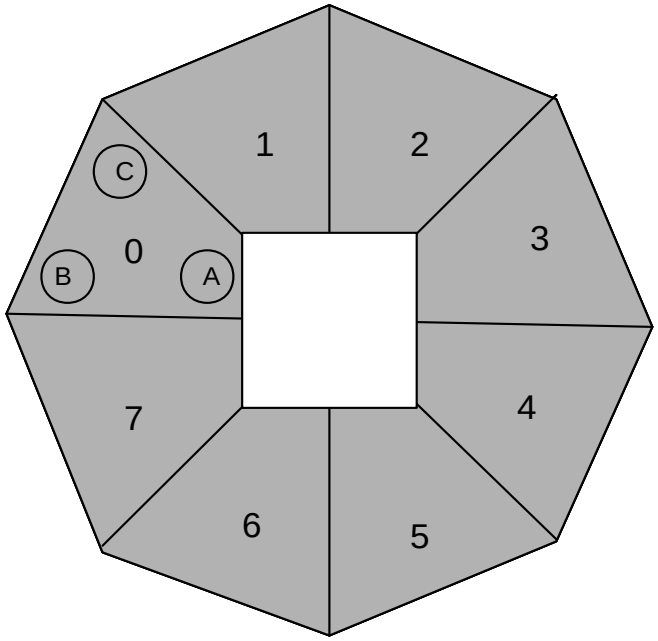
→ efficient use of source

BS-Detector array

Eight NaI(Tl) detectors

Thickness:	16 mm
Array diameter:	≈ 50 cm
Light read-out:	3 PMT





→ BS-efficiency: > 80%

→ Position resolution: ≈ 2 cm

(light division)

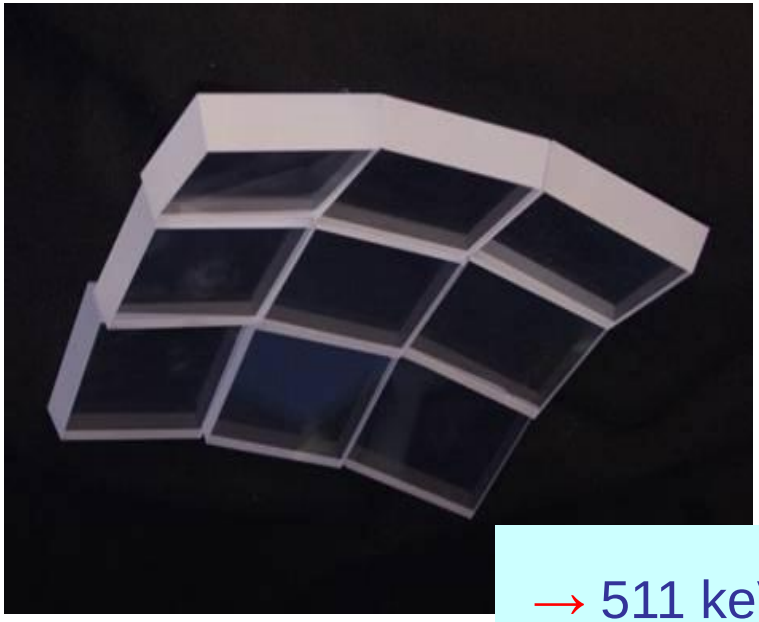
Position-Detector array

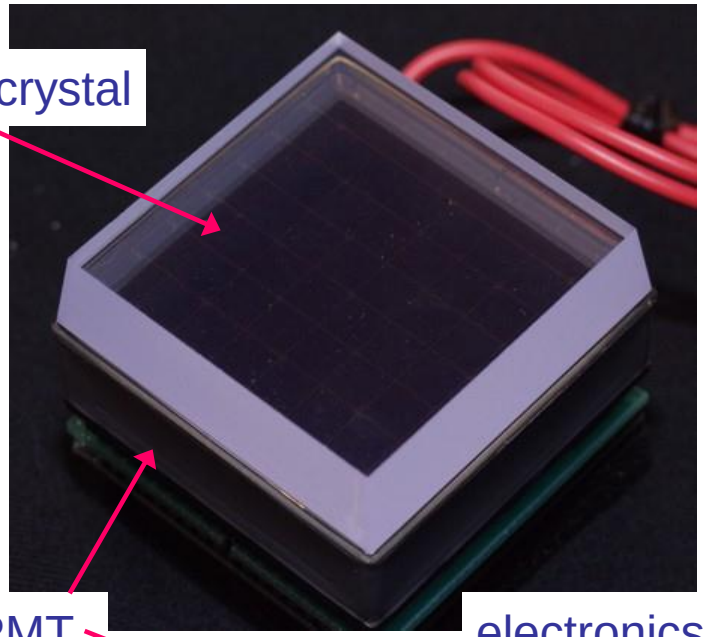
Nine LYSO detectors

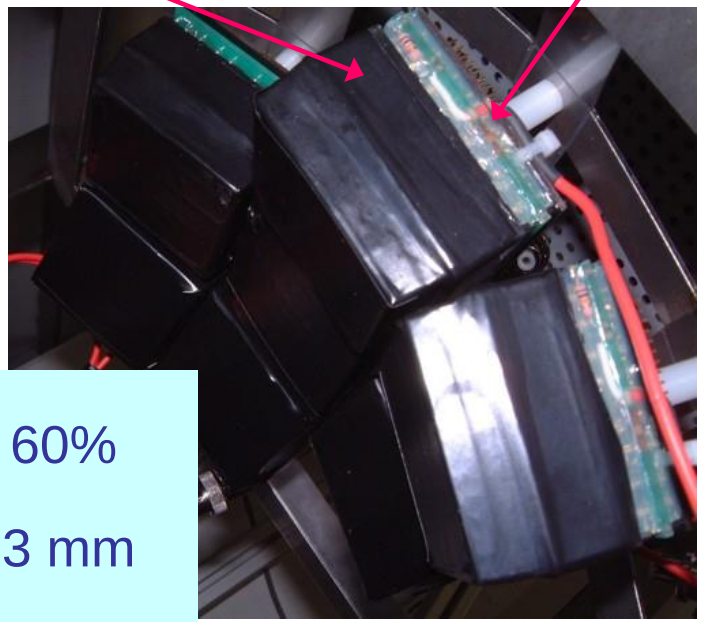
Thickness: 18 mm

Size: 50 x 50 mm^2

Light read-out: 8x8 anode PMT





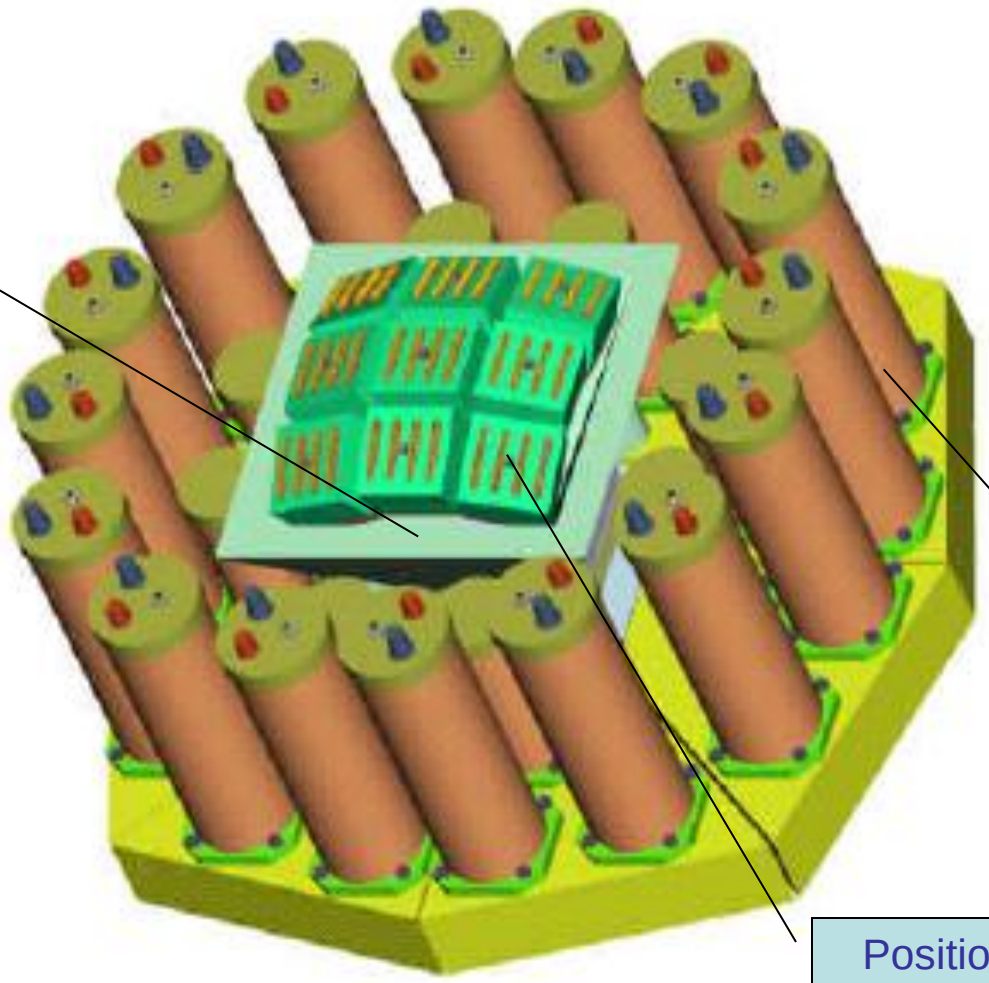


→ 511 keV Efficiency: > 60%

→ Position resolution: ≈ 3 mm

(light division)

Detector arrangement



Shielding of the ^{22}Na source

Backscatter detector

Position detector

Mine-Verificator (prototype)

γ-source: 10 MBq ^{22}Na

field of view: ≥ 20x20 cm^2

max. penetration: 30 cm

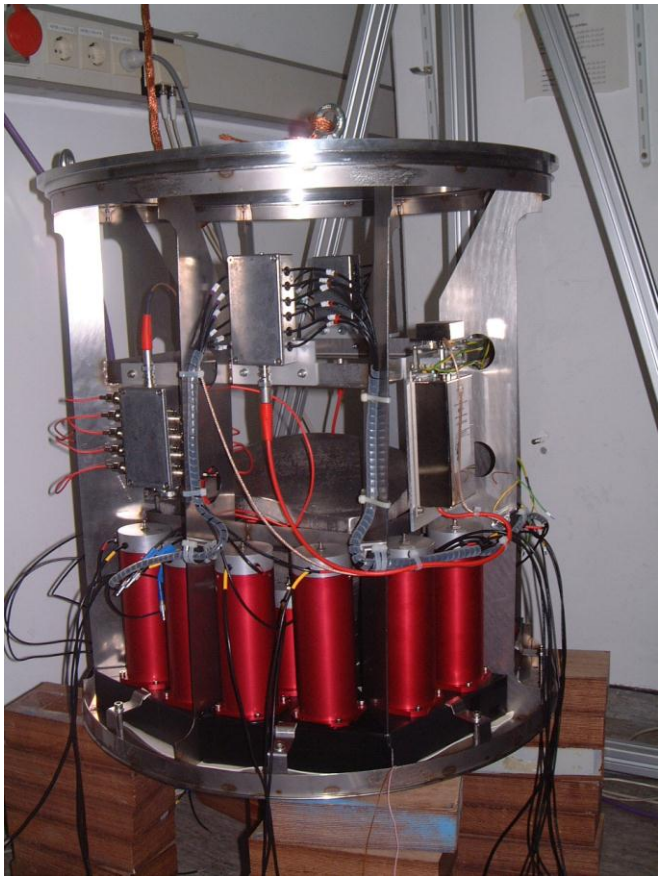
eff. resolution: 60x60 pixels

Position det. rate ≈ 5 MHz

Backscatter det. rate ≈ 500 kHz

Scaled down singles trigger ≈ 500 kHz

Pos-BS coincidences trigger ≈ 150 kHz



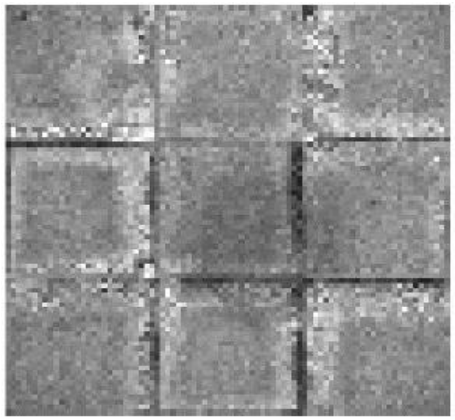
First results

Verification by

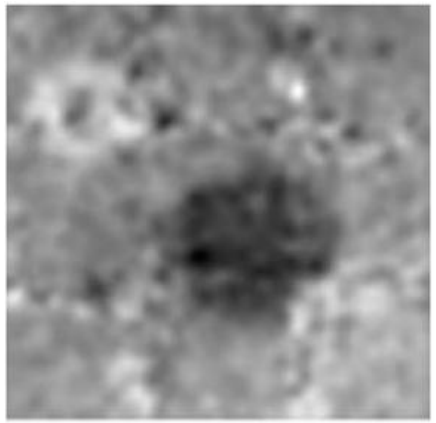
→ Shape

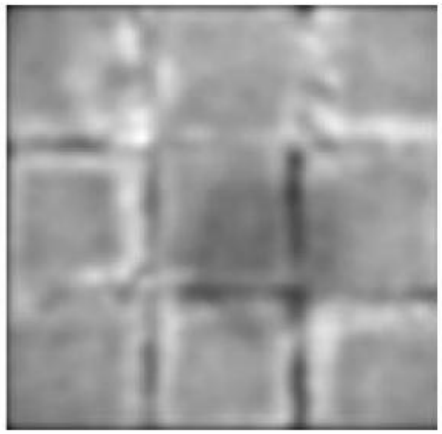
→ Density

Raw data

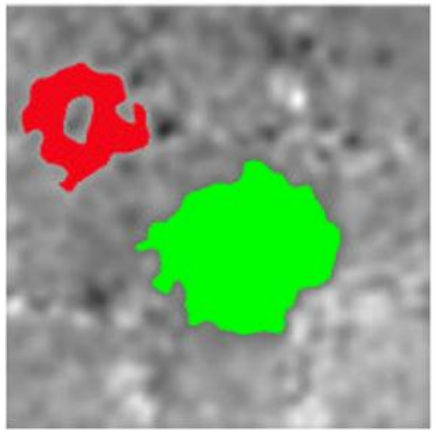


Artefact removal



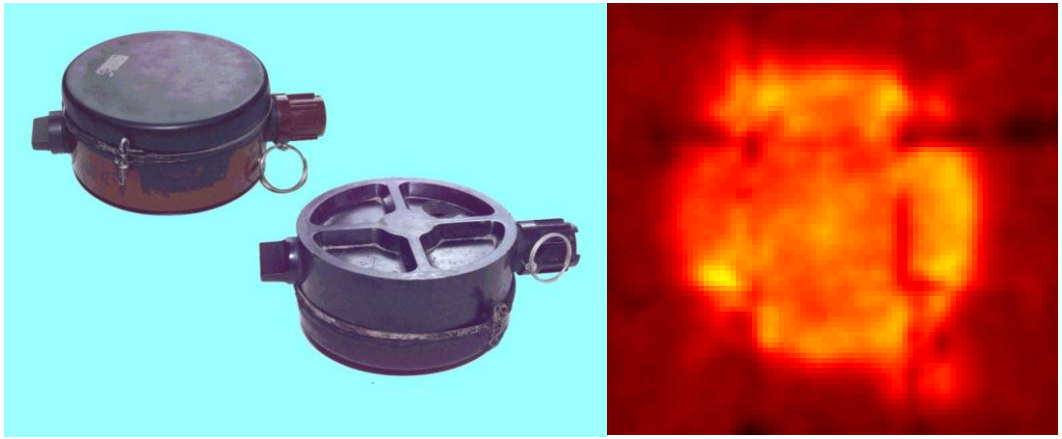


Filtered data

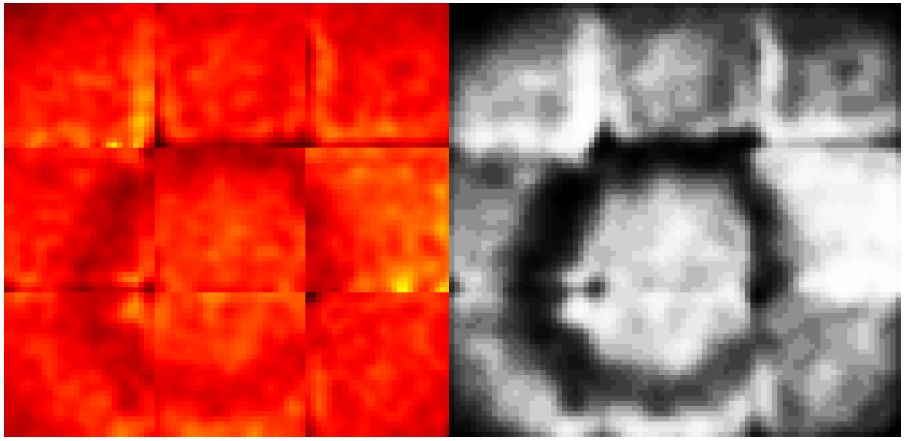


Area segmentation

Mine detection capability



APM covered by
wet sand



ATM in 10 cm soil

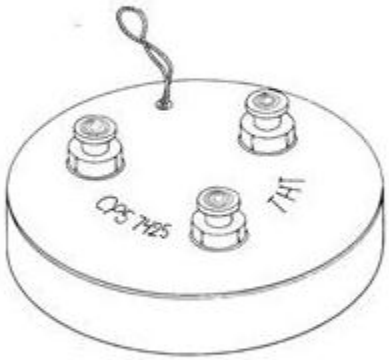
Contrast depends on

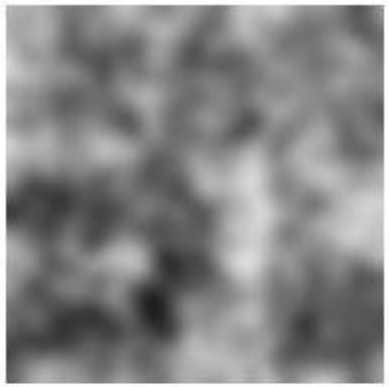
- Soil type and compositions
- Soil humidity

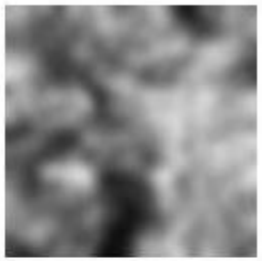
Scanning speed: **5 – 50 m²/d !**

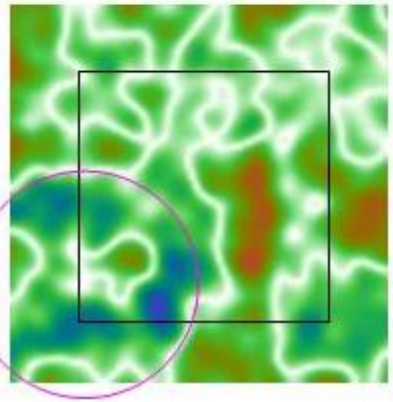
Mine detection in the field

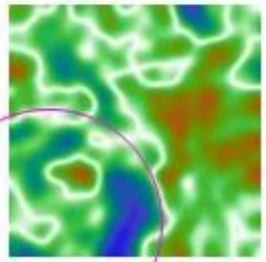
ATM in 10 cm coarse gravel



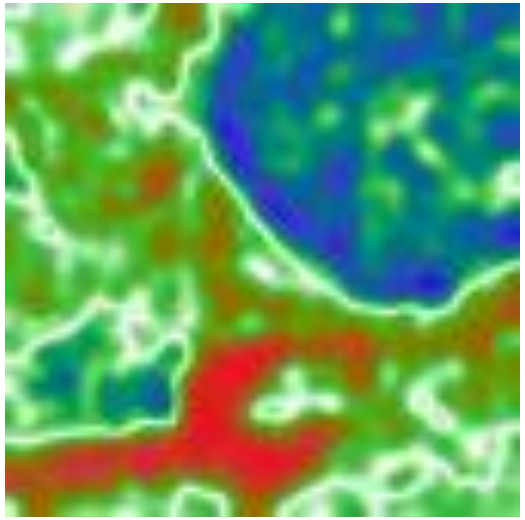




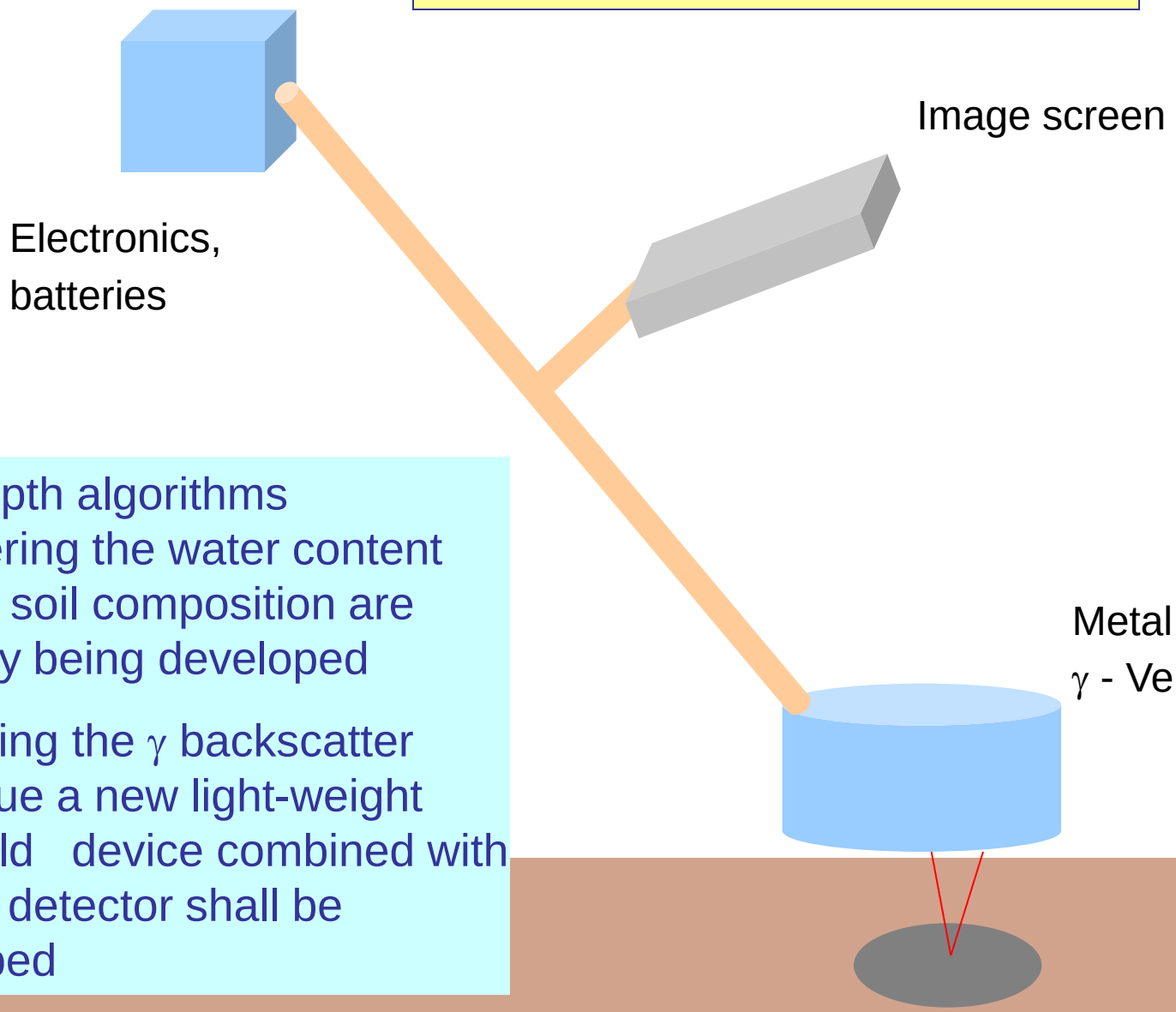




APM in 5 cm clay



Future plans and ideas

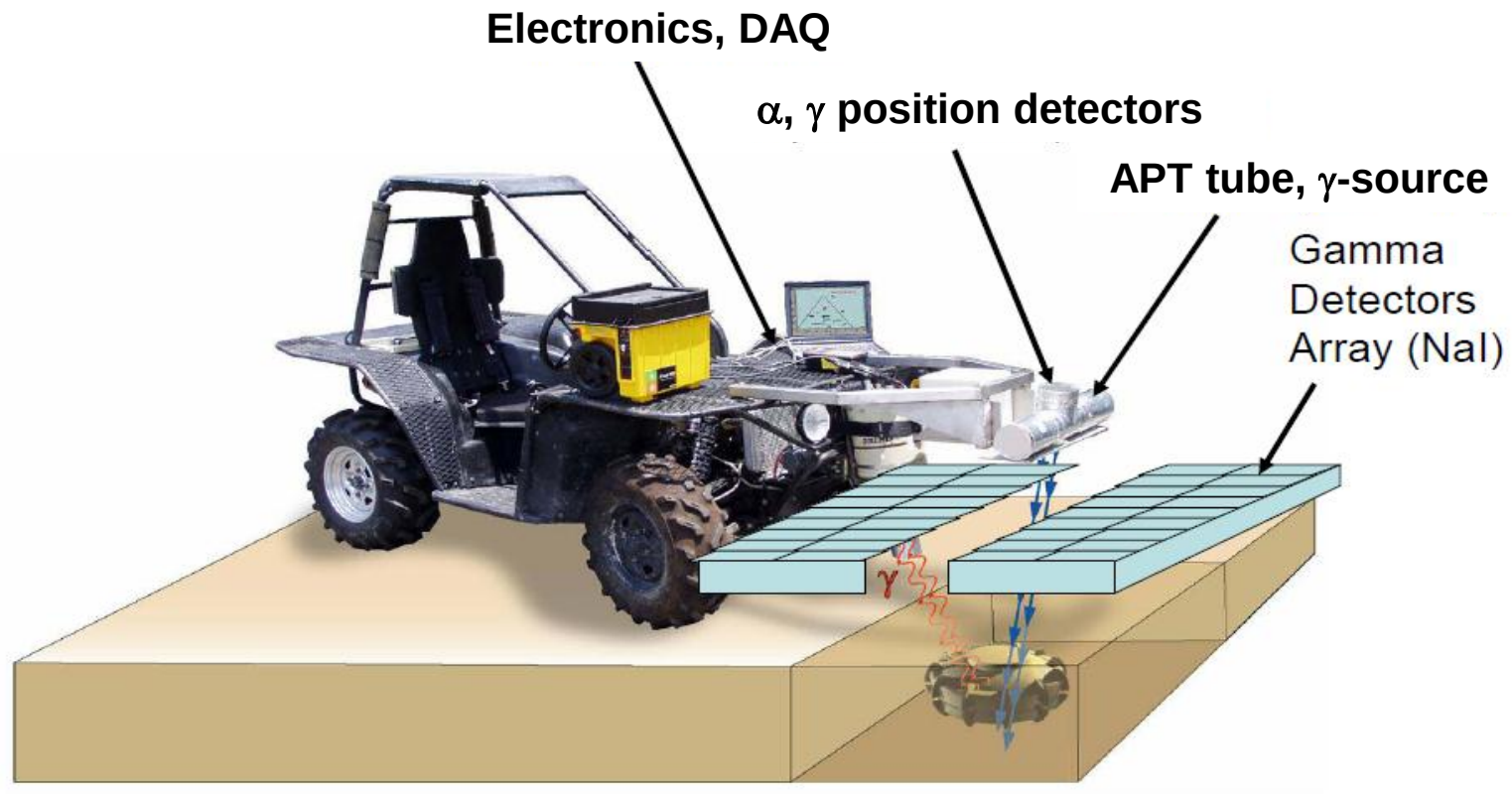


New depth algorithms considering the water content and the soil composition are currently being developed

Employing the γ backscatter technique a new light-weight handheld device combined with a metal detector shall be developed

Future plans and ideas

Fusion of neutron activation and γ backscatter imaging is envisaged to increase the selectivity and sensitvity by combining shape and chemical composition information



Far future plans and ideas

Laser induced directed γ and neutron beams may lead in the future to a considerably improved image quality and much shorter image generation times

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