New developments in High-density Scintillation Crystals for Positron Emission Tomography

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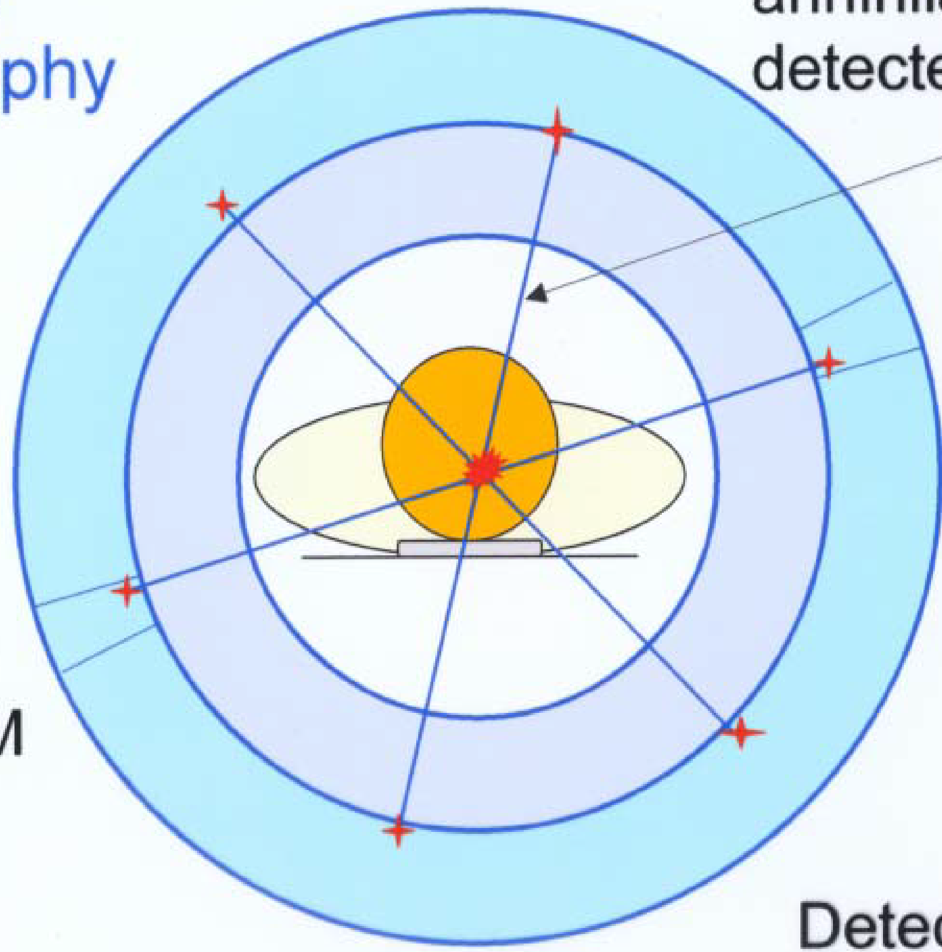
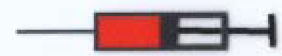
Positron Emission Tomography

Collinearly emitted annihilation quanta detected in coincidence





Radiopharmacon

Detectors
BGO + PM

Detector ring
(inner diam. ~ 0.8 m)

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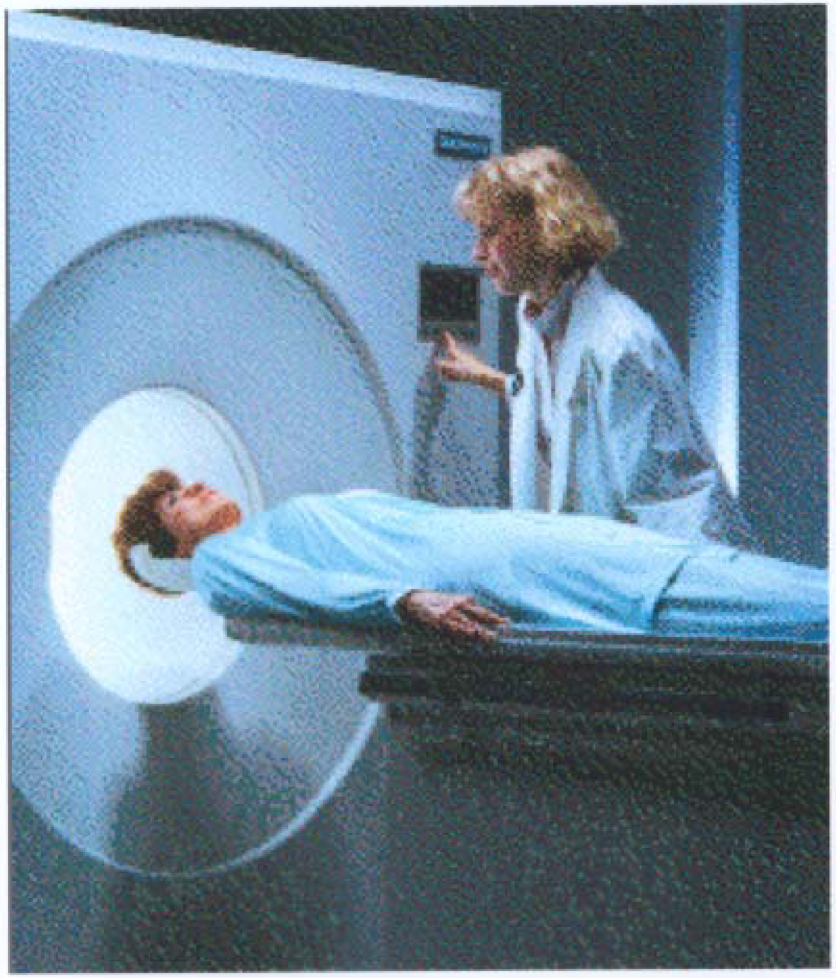
Radiation in Medicine — Diagnostics



http://www.epub.org.br/cm/n01/pet/pet_hist.htm

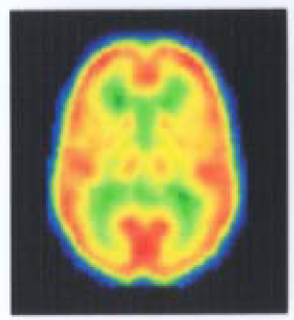
PET III
1975

ECAT II
1977

NeuroECAT
1978

ECAT 931
1985

ECAT EXACT HR+
1995



Siemens-CTI
PET systems

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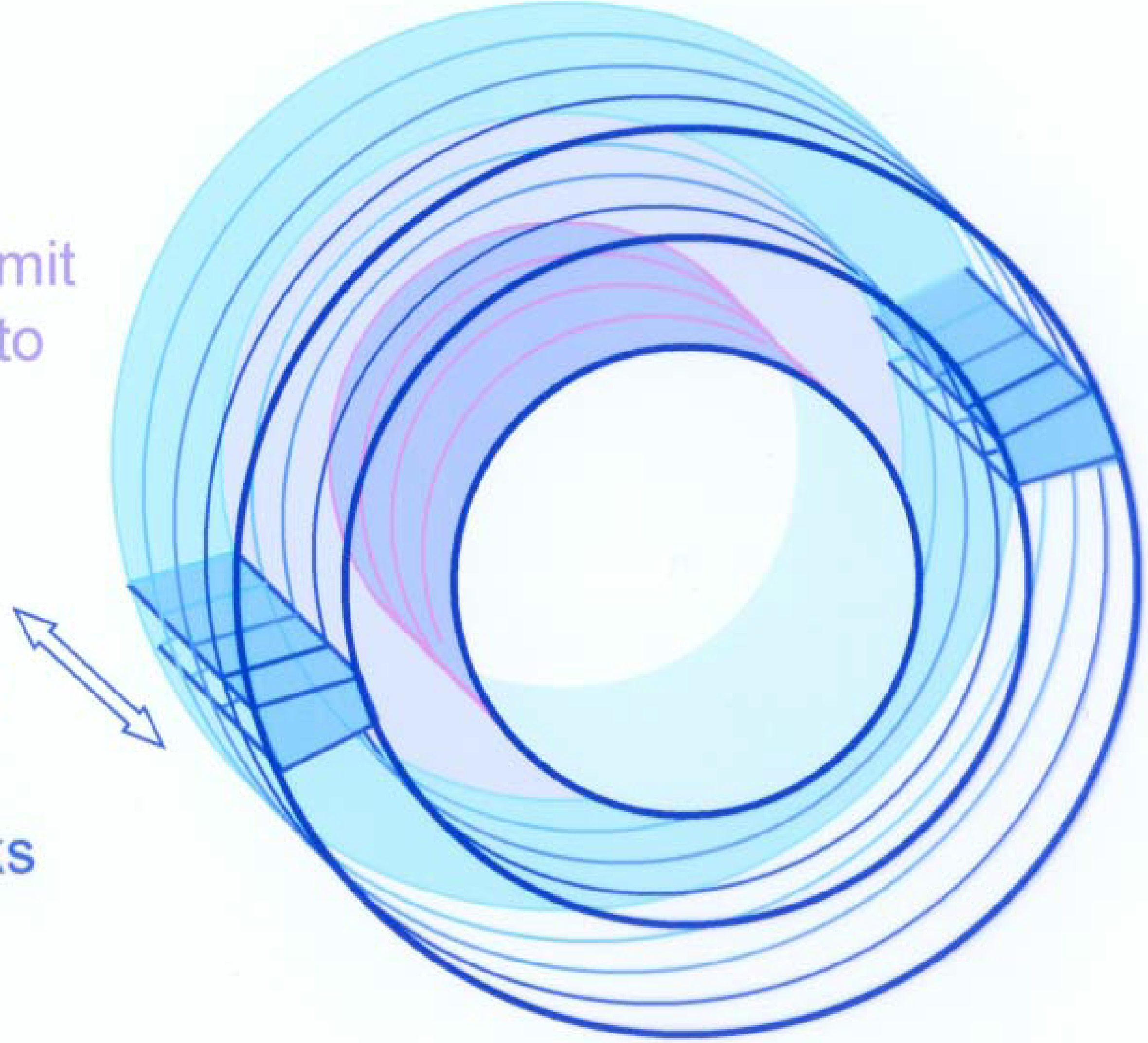
PET
multi layer

tungsten septa limit
cross-plane hits to
~ 4 - 6 planes
if removed: 3D



24 - 48 layers
in rings of
detector blocks

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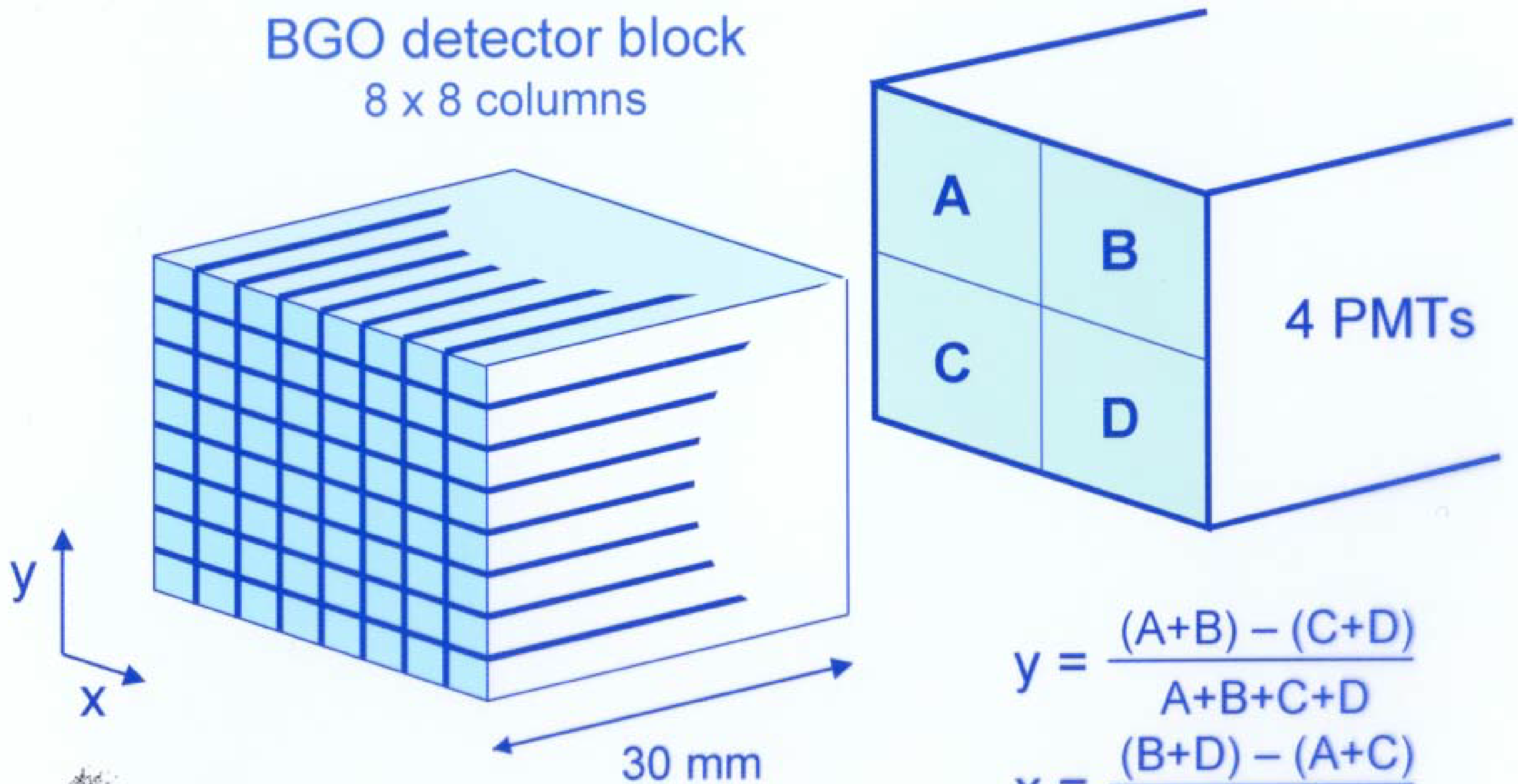
PET - multi layer



$$y = \frac{(A+B) - (C+D)}{A+B+C+D}$$

$$x = \frac{(B+D) - (A+C)}{A+B+C+D}$$

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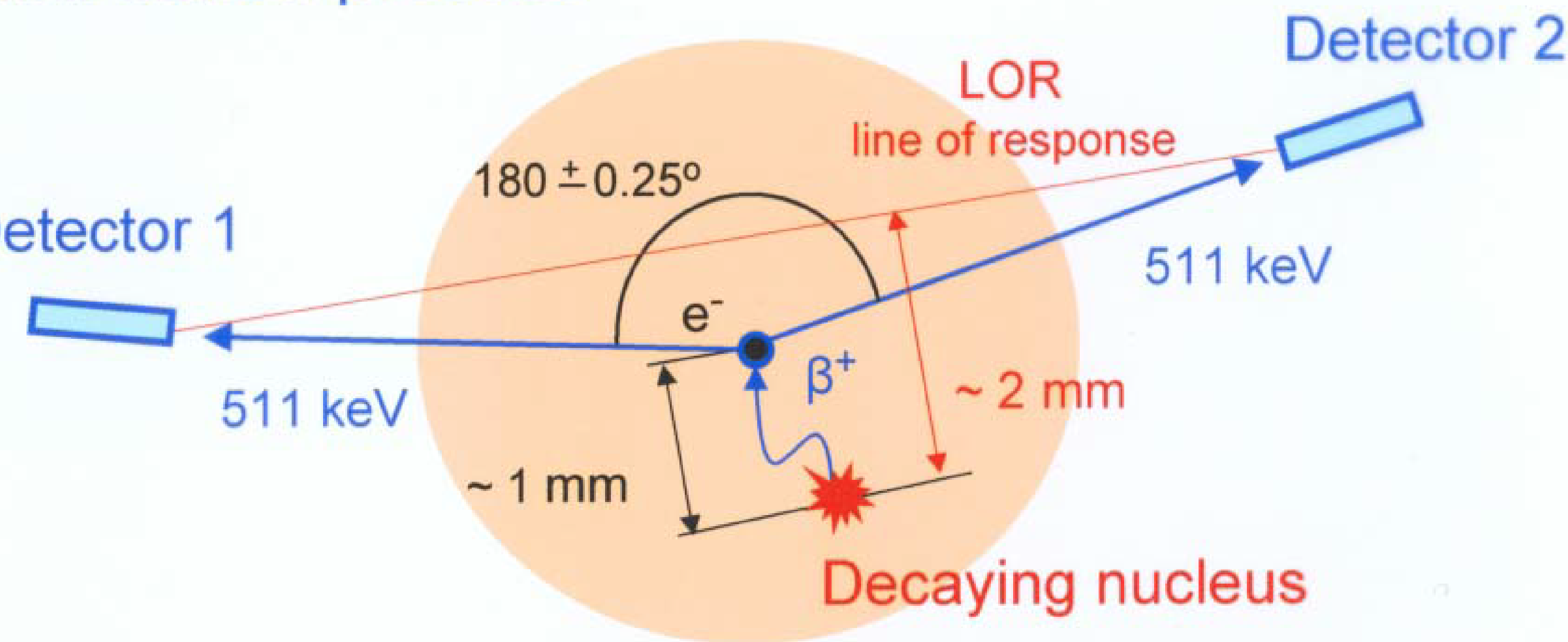
PET
Annihilation process



Due to physics:
inaccuracy in reconstructed position
decaying nucleus ~ 2 mm

PET radionuclides

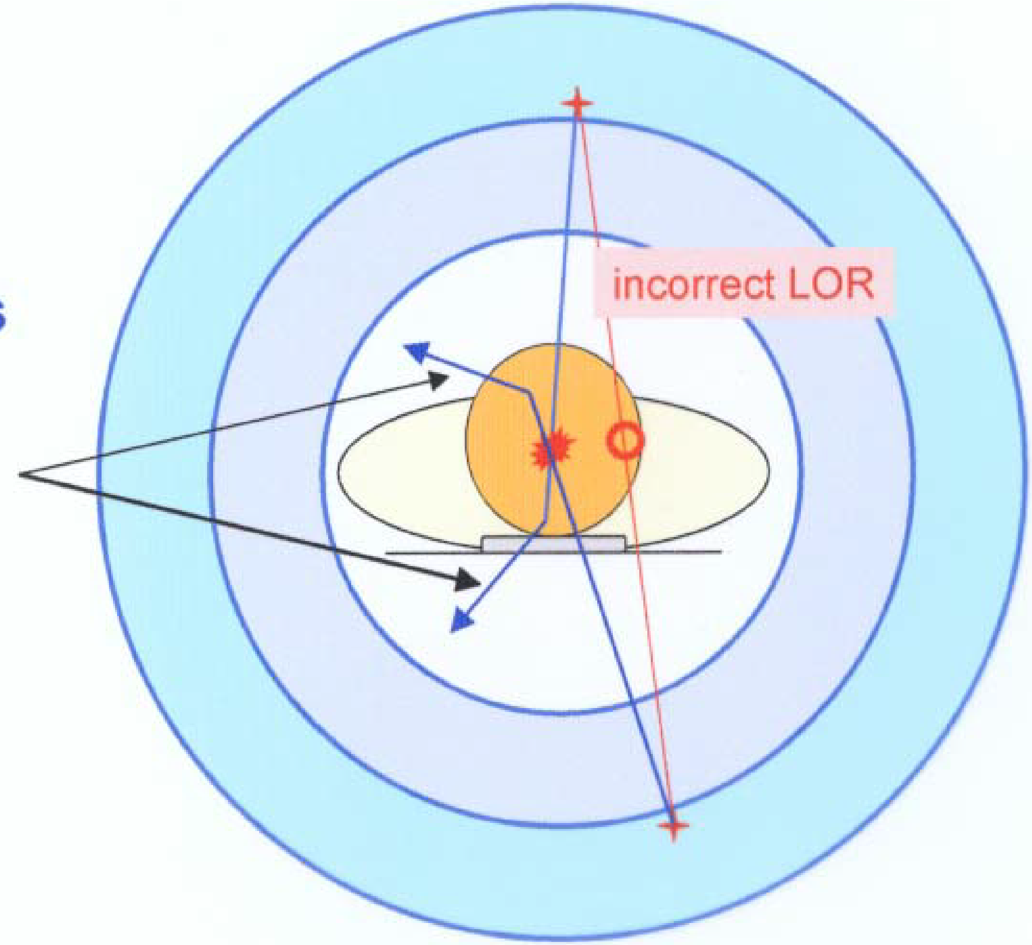
	production	half life (min)	max/aver β^+ energy (keV)	range in tissue (mm)	intrinsdic resolution FWHM (mm) for system diam. 0.8 m
^{11}C	$^{14}N(p,\alpha)$	20.4	960/	0.28	2.0
^{13}N	$^{13}C(p,n)$	9.96	1190/		
^{15}O	$^{15}N(p,n)$	2.07	1730/		
^{18}F	$^{18}O(p,n)$	109.7	633/	0.22	2.0
^{68}Ga	$^{68}Ge(EC)$	68.1	1898/	1.35	3.0
^{82}Rb			3150/		

F substitutes for H

PET sources of error

random coincidences

scattering out of system



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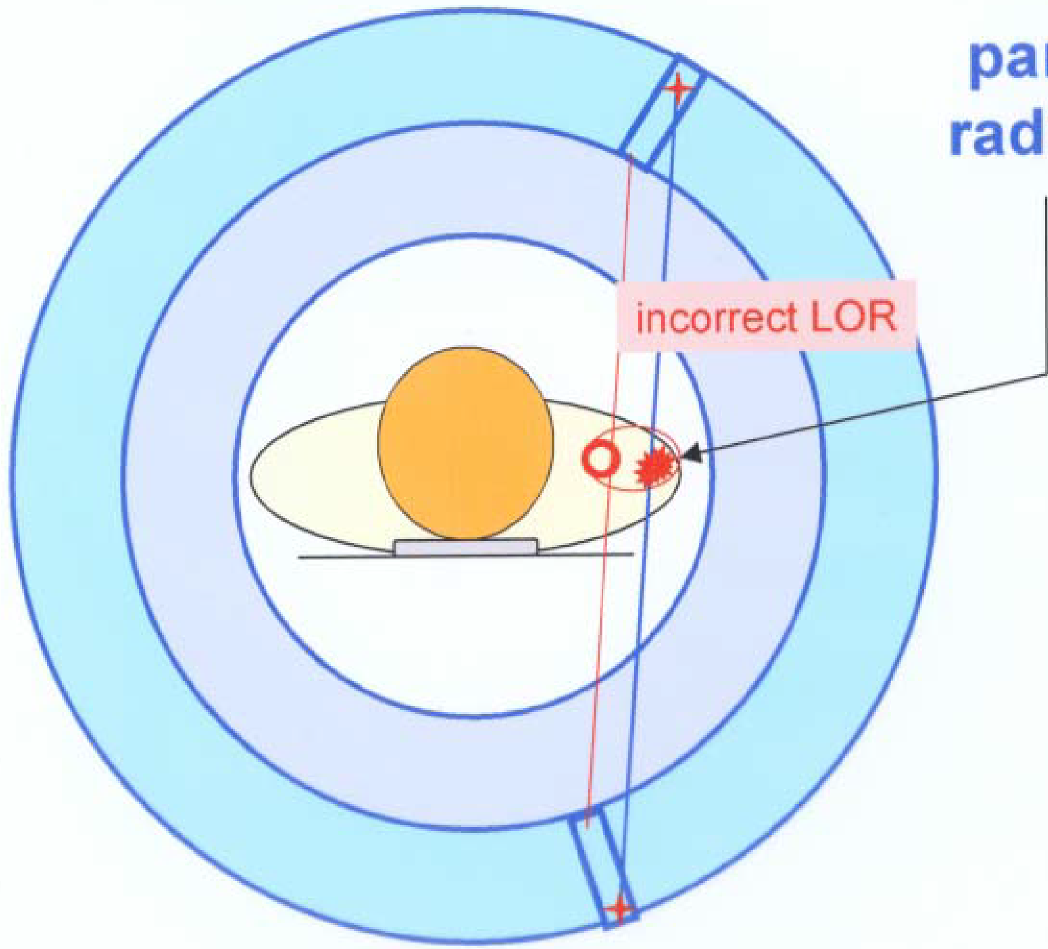
PET sources of error

Off centre:
parallax error or
radial elongation



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PET sources of error

Off centre:
parallax error or
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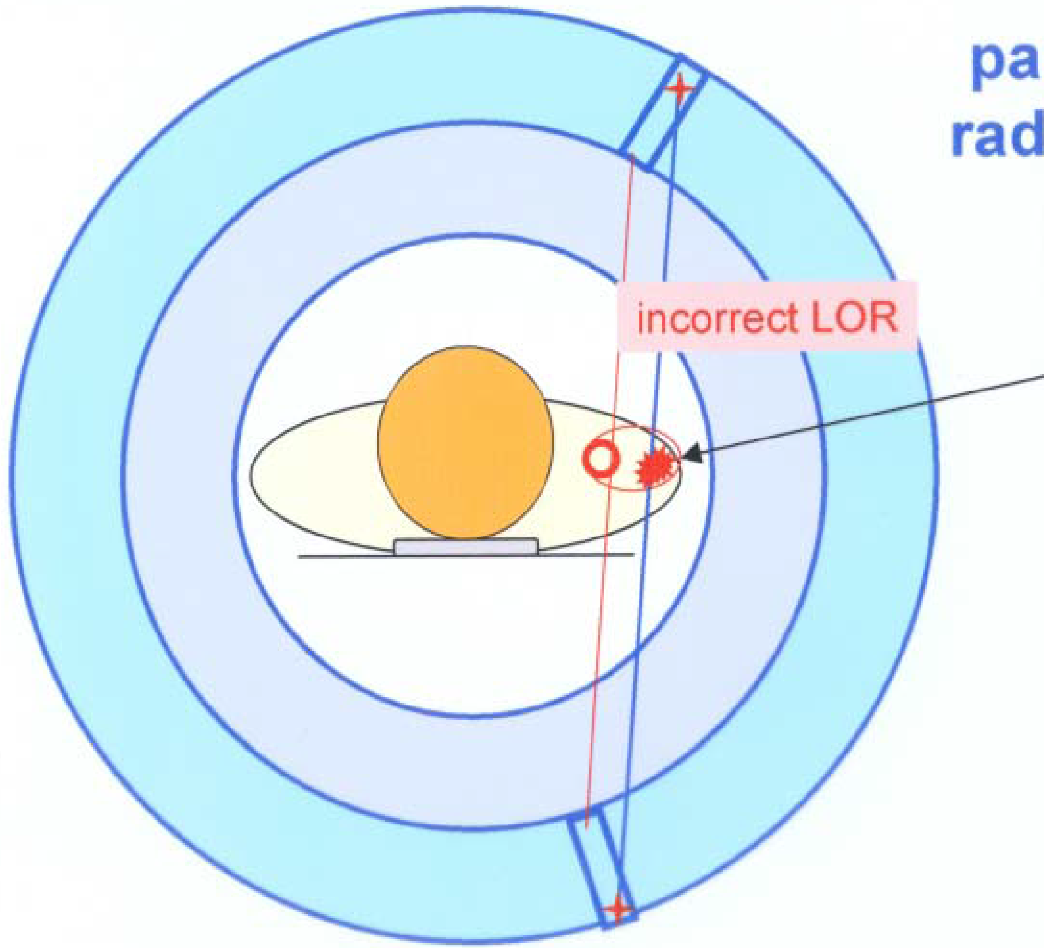

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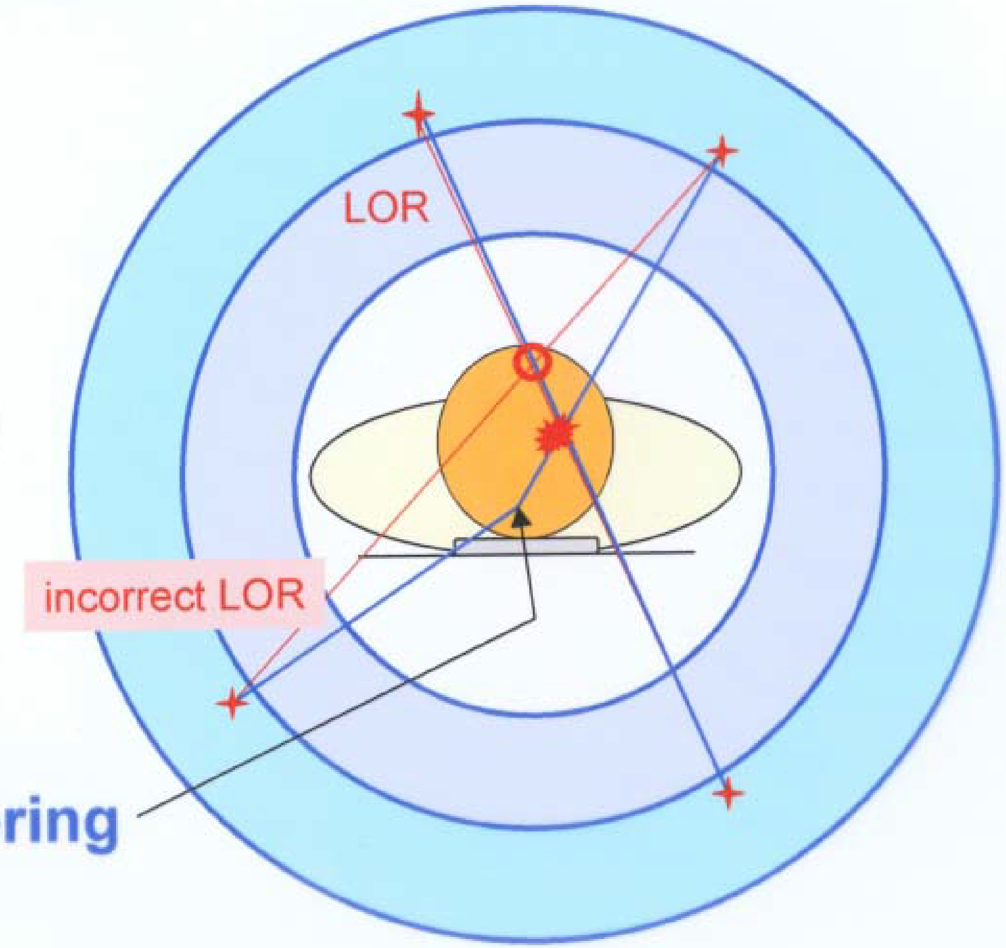
PET sources of error



PET system requirements

- detection eff. ε high — coinc. eff. $\propto \varepsilon^2$
- aspects of time
  - time resol. $\Delta t \leq 1$ ns: — random coinc. $\propto \Delta t$
  - if very small, TOF information: — 100 ps $\equiv$ 15 mm
  - response time and electronics: — dead time
- pos. resol.: ~ 5mm → ~ 3 mm — parallax error!
- energy resol. good: — Compton scattering!
- other quality aspects, low cost

PET system requirements ⟹ detector

- detection efficiency ε 511 keV HIGH

⇓

high density
high Z

⇓

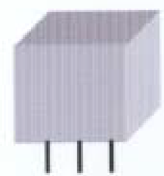
inorganic scintillator

PET system requirements ⟹ detector

- time resolution
- position resolution
- energy resolution

} $\propto 1/N_{photon}^{1/2}$

N_{photon} ⟹ **Large**

N_{photon} →  → $N_{electron}$

light sensor

matching

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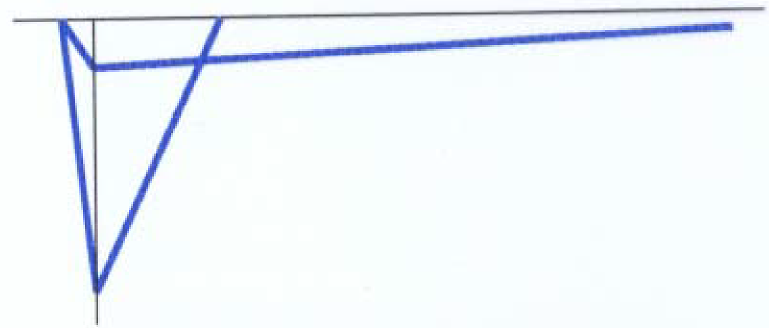
PET system requirements ⟹ detector

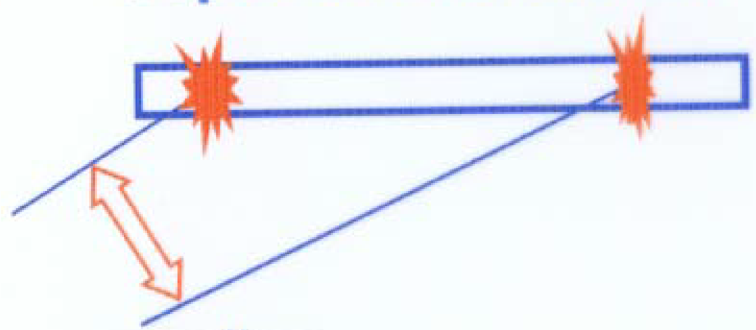
- time resolution

scintill. decay time τ **short**



- position resolution

depth of interaction



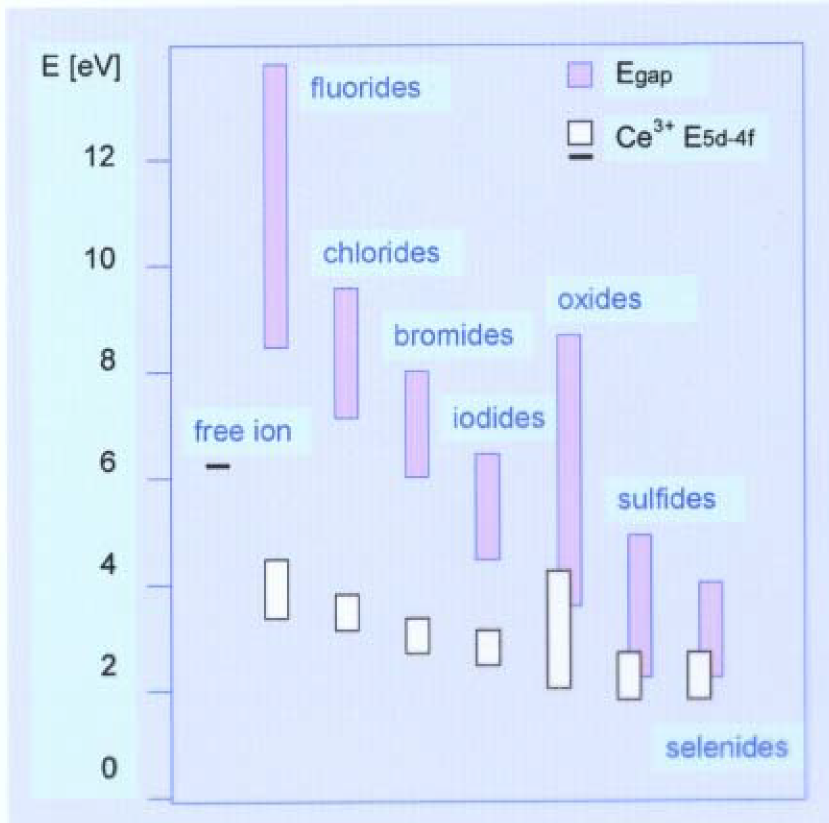
Inorganic scintillator

- Select interaction medium: **host material**
  - high density
  - high Z
  - small E_{gap} (many photons)
  - accomodates dopant
  - quality aspects
- Select **dopant** as Luminescence Centre with
  - efficient luminescence
  - fast response

→ **Ce^{3+}** ions

Inorganic scintillator

Ce^{3+} levels and E_{gap}



PET scintillators

	ρ (g/cm³)	atten.length 511 keV (mm) /PE prob. (%)	light yield (photons/MeV)	τ (ns)	λ (nm)
$Bi_4Ge_3O_{12}$ (BGO)	7.1	11.6 / 44	9,000	300	480
Lu_2SiO_5:Ce (LSO)	7.4	12.3 / 34	26,000	40	420
$LuAlO_3$:Ce (LuAP)	8.3	11.0 / 32	12,000	18	365
$Lu_2Si_2O_7$:Ce (LPS)	6.2	14.5 /	20,000	30	380
Lu_2S_3 :Ce	6.2	14.0 /	28,000	32	590
Gd_2SiO_5:Ce (GSO)	6.7	15 / 26	8,000	60	440

LuAP:Ce

Minkov, 1994
Lempicki et al. 1995
Moses et al. 1995
Mares et al. 1995
Crystal Clear Collaboration

Problem

near melting point ~ 2100 °C

$LuAlO_3 \rightarrow Lu_3Al_5O_{12}$

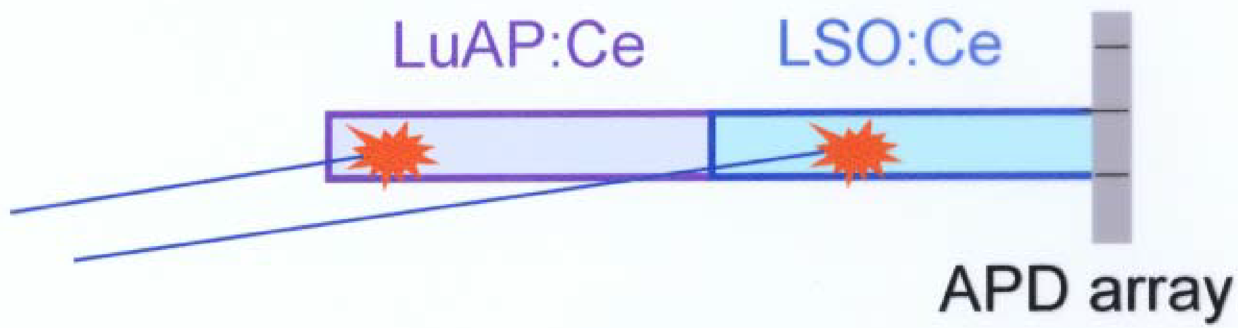
Needed

Systematic studies to grow
high quality crystals
for PET

⇨ Crystal Clear Collaboration
Prague Group + Crytur
Bogoroditsk, Russia

Why LuAP development? LSO is not bad !

Depth of interaction



Pulse shape discrimination

Saoudi et al. IEEE Trans. Nucl. Sci 46(1999)462, also 479
Seidel et al. IEEE Trans. Nucl. Sci 46(1999)485

Conclusion

Introduction of new applicable scintillators is difficult job, but

possible

LuAP:Ce will most likely contribute to

improvement of PET