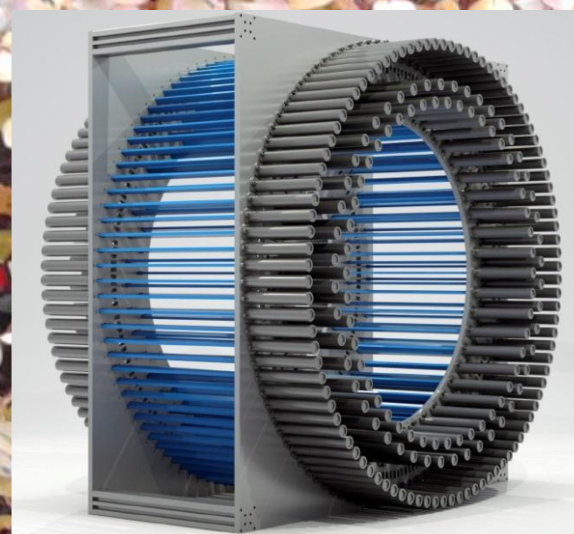
Wgląd w naturę materii za pomocą anihilacji cząstek

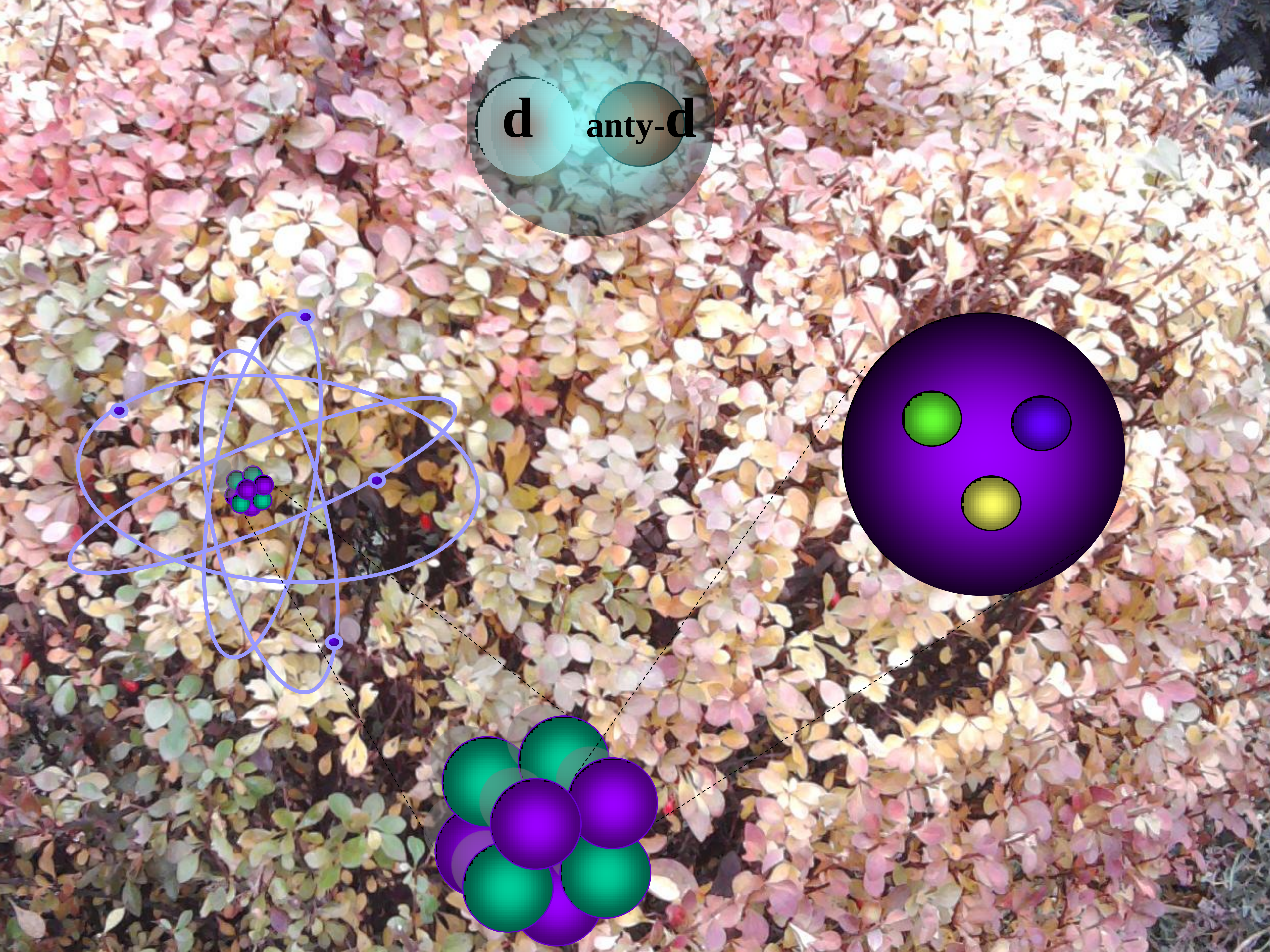


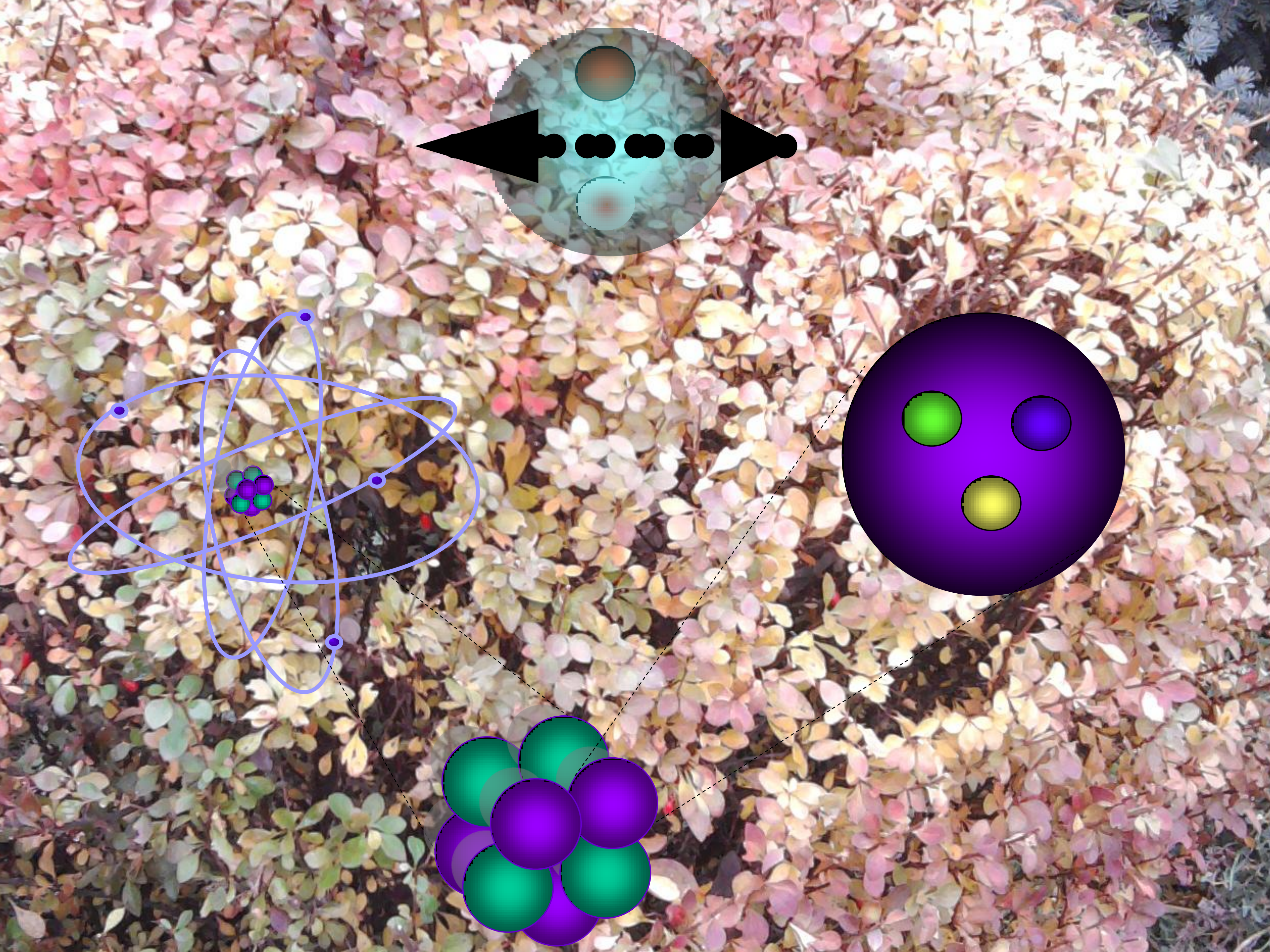
Jagiellonian PET

Seminarium, Wydział WFiIS AGH, 8 kwietnia 2015

Paweł Moskal, Uniwersytet Jagielloński

- materia -- anty-materia
- ciemny foton
- Jagiellonian PET
- symetrie dyskretne
- nano-struktura komórek


d
anty-d

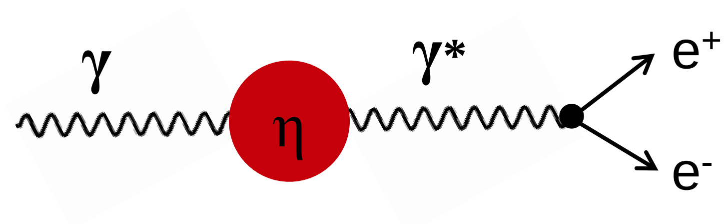


E. Czerwiński, P.M. et al., Phys. Rev. Lett. 113 (2014) 062004

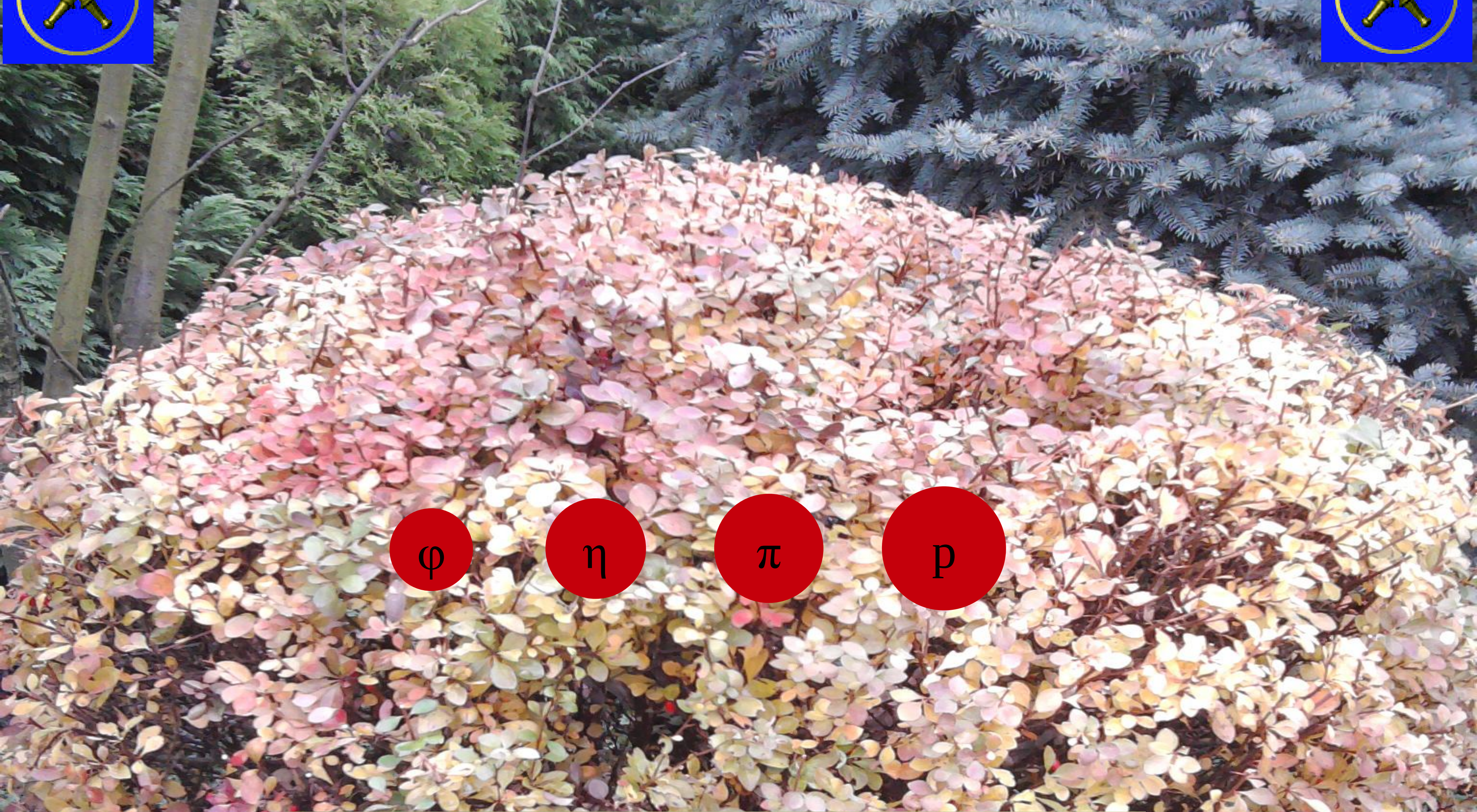
E. Czerwiński, P.M. et al., Phys. Rev. Lett. 105 (2010) 122001

R. Czyżykiewicz, P.M. et al., Phys. Rev. Lett. 98 (2007) 122003

P.M. et al., Phys. Rev. Lett. 80 (1998) 3202


γ
η
γ*
e+
e-

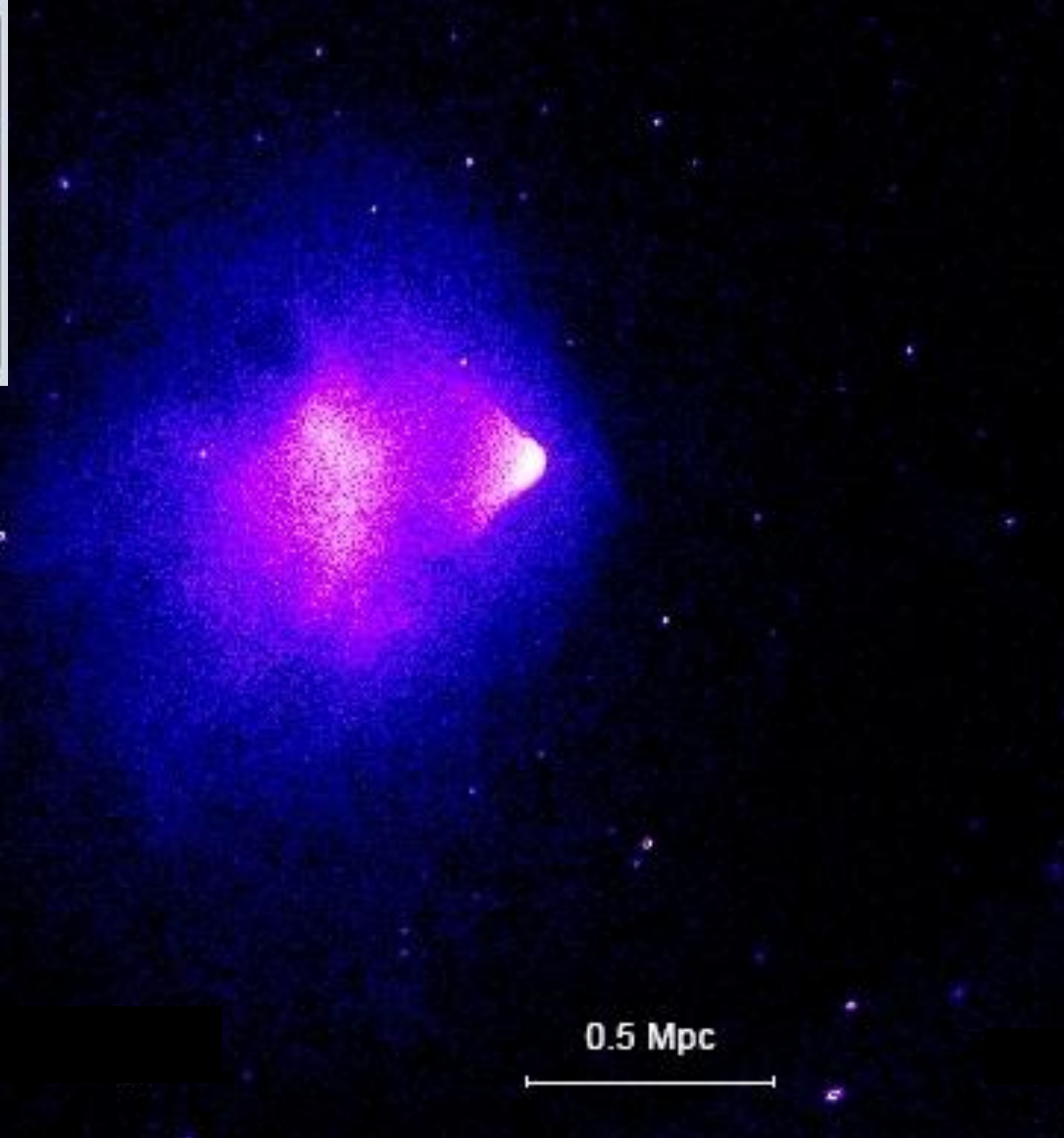
rozmiary hadronów



R. Pohl et al., The size of the proton, Nature 466 (2010) 213
A. Liesenfeld et al., Phys. Lett. B468 (1999) 20

Czynniki postaci: J. Zdebik PhD JU (2013); M.Hodana PhD JU (2012)

CHANDRA SATELLITE



chandra.harvard.edu

Princess Elisabeth of Bohemia writes on 10.vi.1643:

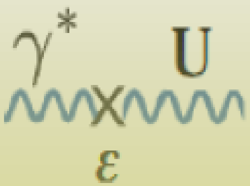
„…I don’t see how the idea that you used to have about weight can guide us to the idea we need in order to judge **how the (nonextended and immaterial) soul can move the body”**

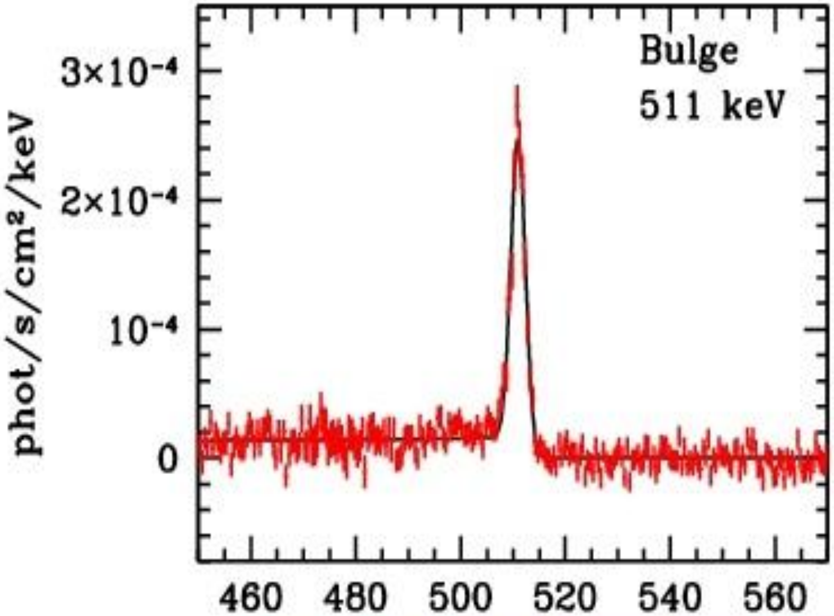
Descartes writes on 28.vi.1643:

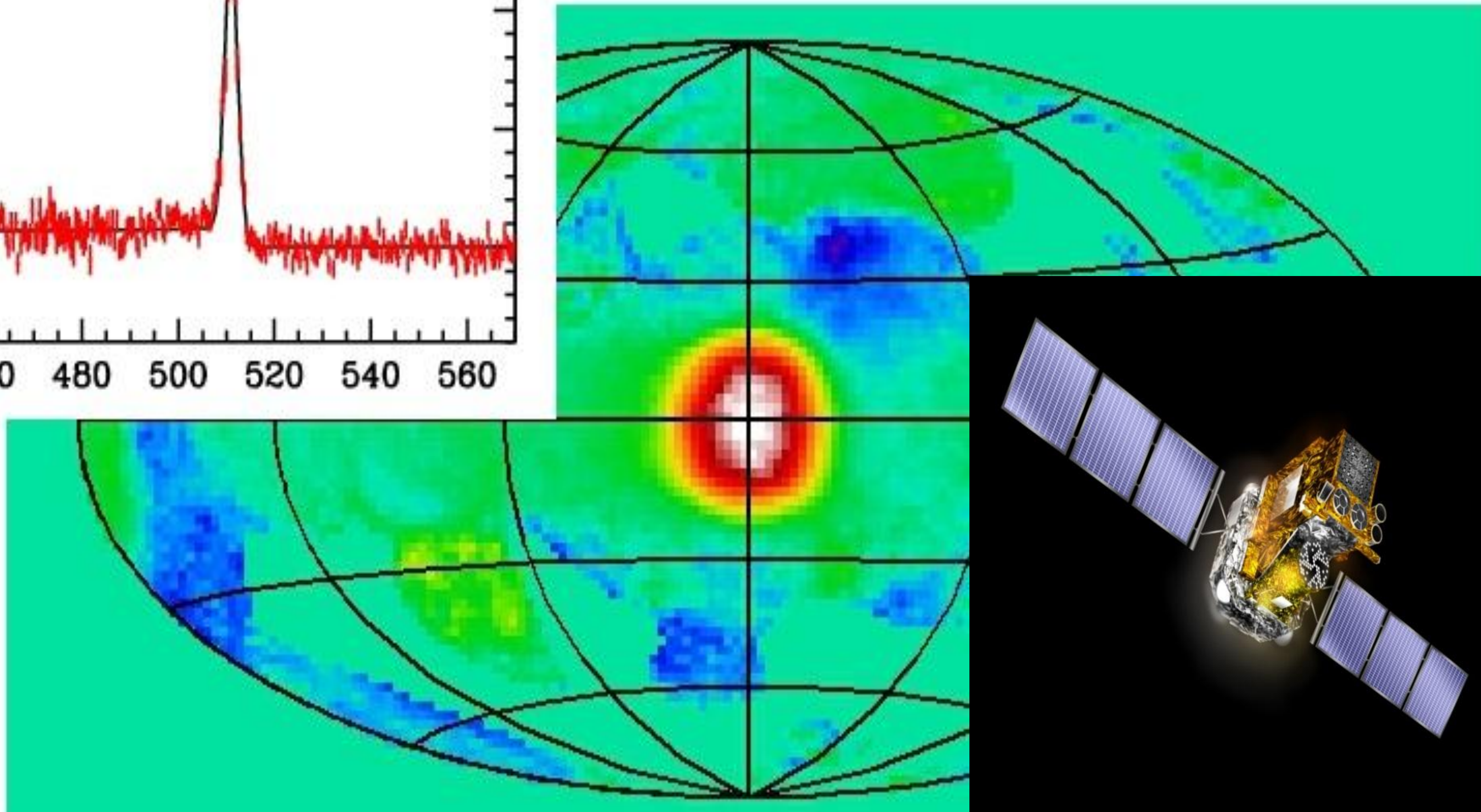
„…I ought to have made clear that although one may wish to think of the soul as material (…), that wouldn’t stop one from realizing that the soul is separable from the body. I think that those cover everything that you asked me to do in your letter.”

Particle physics four centuries later:
How the „non-SM dark matter” can move the „SM matter” ?:

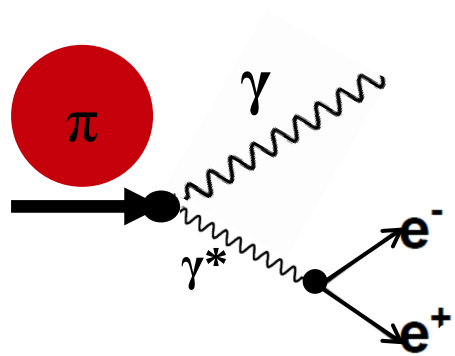
$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4}F^{dark}_{\mu\nu}F^{\mu\nu}_{dark} - \frac{\epsilon}{2}F^{dark}_{\mu\nu}F^{\mu\nu} + |D^{\mu}\phi|^2 - V(\phi)$$



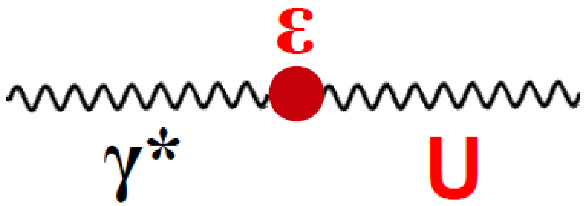




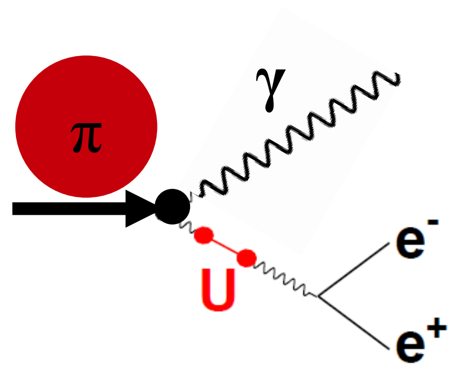
INTEGRAL SATELLITE



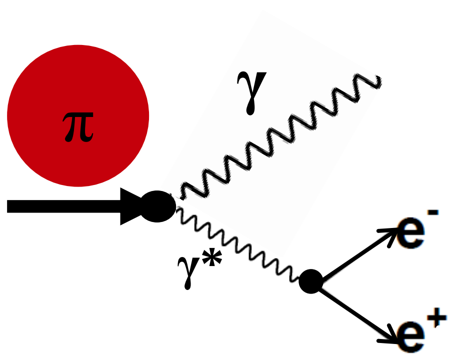
π
γ
γ*
e-
e+



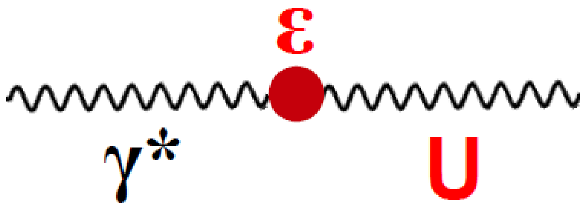
ε
γ*
U

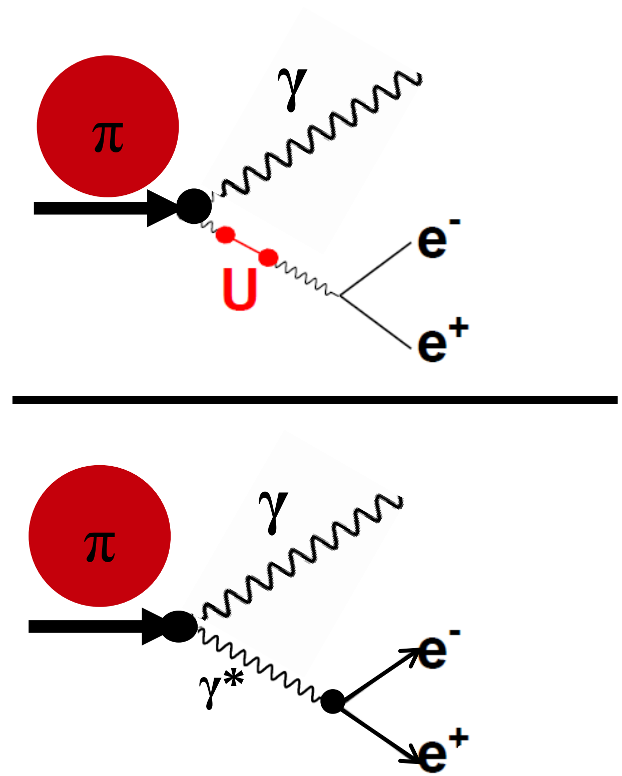


π
γ
e-
U
e+



π
γ
e-
γ*
e+





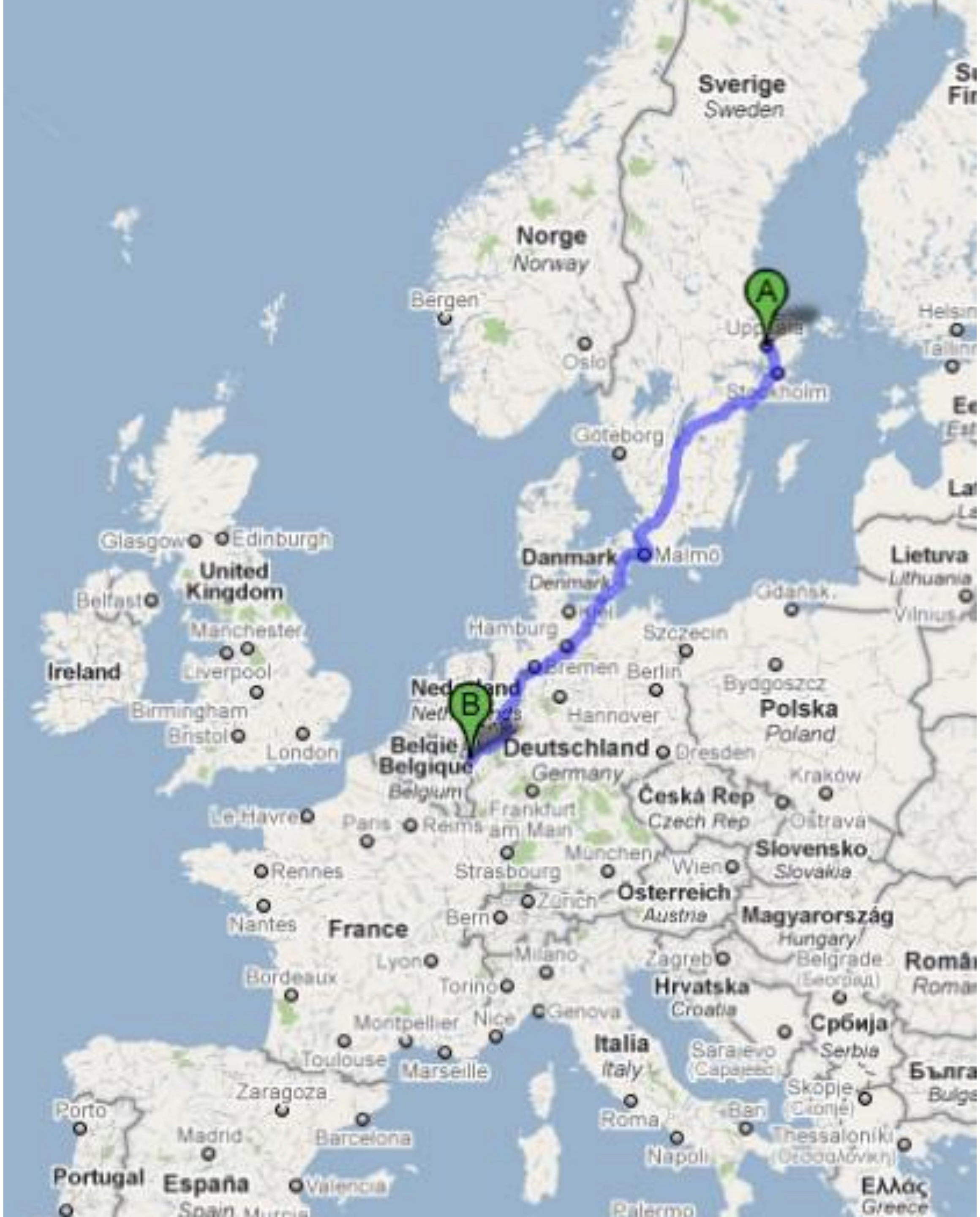
$=\sim \dots \varepsilon^2 \dots$

WASA-at-COSY

$10^9\,\eta$ and $10^{11}\,\pi^0$

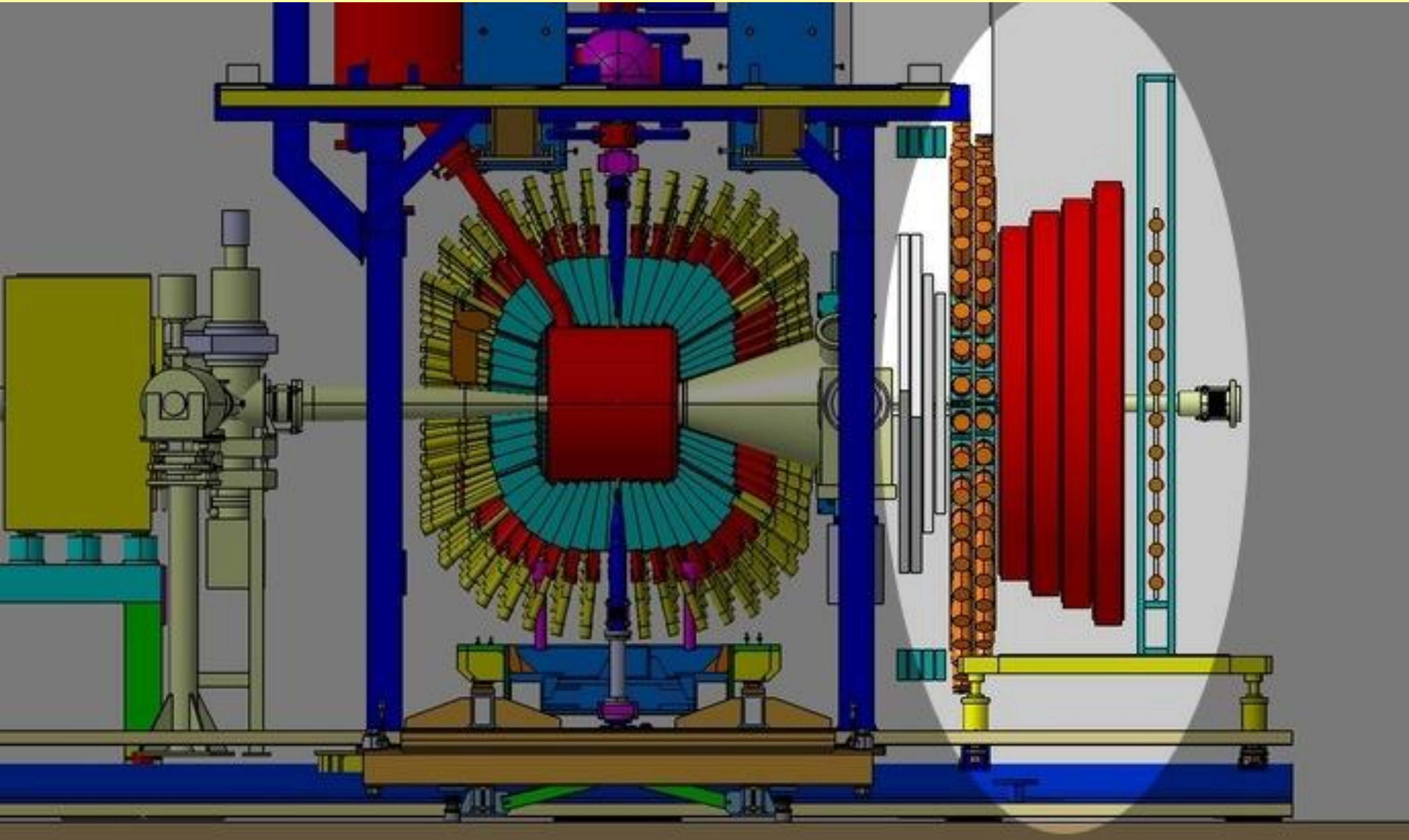
WASA

A WARSHIP built for the war with Poland
which sank in 1628 in the middle of Stockholm harbour
after sailing barely 1300 meters


A
B
Sverige
Sweden
Norge
Norway
Bergen
Oslo
Stockholm
Göteborg
Malmö
Danmark
Denmark
Kiel
Hamburg
Bremen
Hannover
Berlin
Szczecin
Gdańsk
Bydgoszcz
Polska
Poland
Lietuva
Lithuania
Vilnius
Helsinki
Tallinn
Glasgow
Edinburgh
United Kingdom
Belfast
Manchester
Liverpool
Ireland
Birmingham
Bristol
London
Nederland
Netherlands
België
Belgique
Belgium
Deutschland
Germany
Dresden
Kraków
Česká Rep
Czech Rep
Ostrava
Frankfurt am Main
Le Havre
Paris
Reims
Strasbourg
München
Wien
Slovensko
Slovakia
Rennes
Nantes
France
Bern
Zürich
Österreich
Austria
Magyarország
Hungary
Lyon
Milano
Zagreb
Belgrade
(Београд)
Bordeaux
Torino
Hrvatska
Croatia
Montpellier
Nice
Genova
Србија
Serbia
Toulouse
Marseille
Italia
Italy
Sarajevo
(Сарајево)
Zaragoza
Skopje
(Скопје)
Porto
Roma
Bari
Madrid
Barcelona
Thessaloniki
Napoli
Portugal
España
Spain
Valencia
Ελλάς
Greece
Palermo

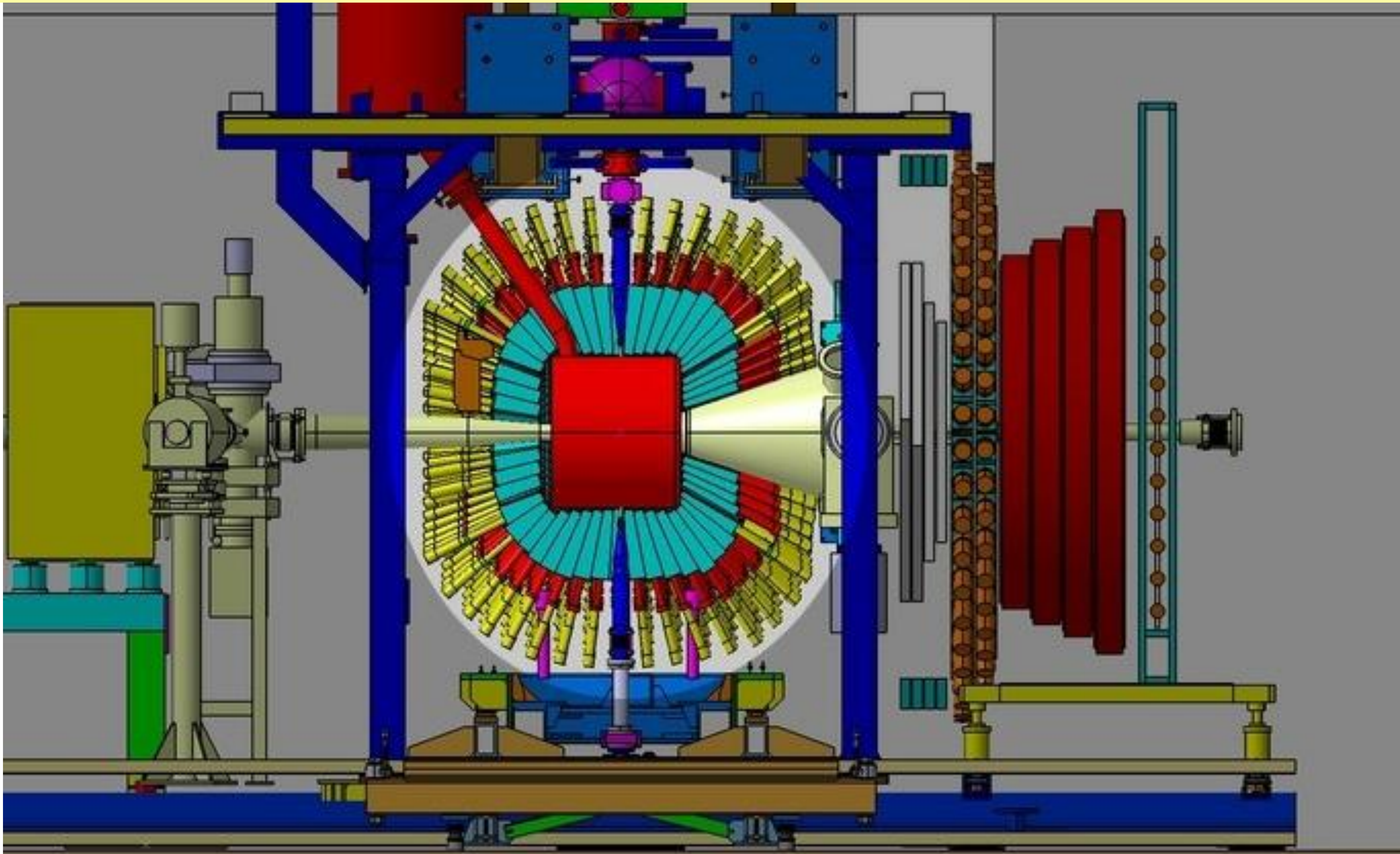
WASA-at-COSY

pp → pp η **pd → ^{3}He η**



WASA-at-COSY

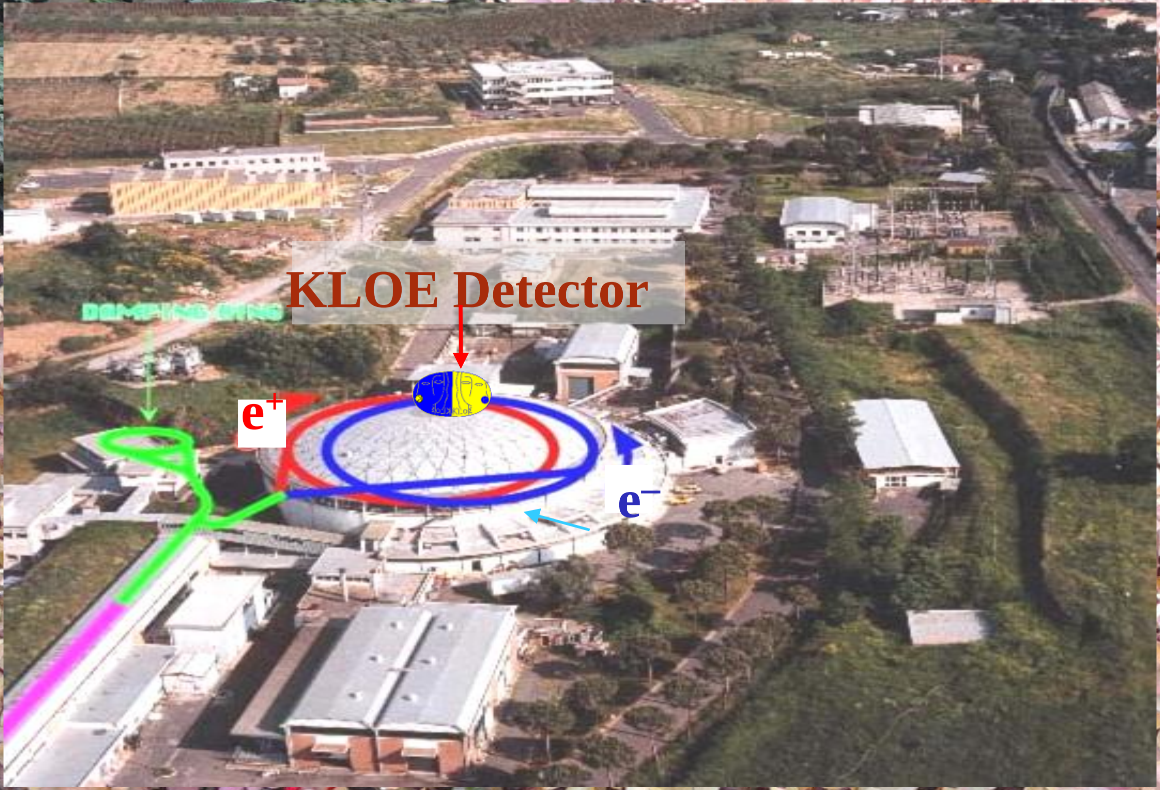
$pp \rightarrow pp\,\eta$ $\qquad$ $pd \rightarrow {}^3He\,\eta$



WASA-at-COSY

$pp \rightarrow pp\,\eta$ $pd \rightarrow {}^{3}He\,\eta$

DAΦNE e^+e^- collider Frascati (Rome)

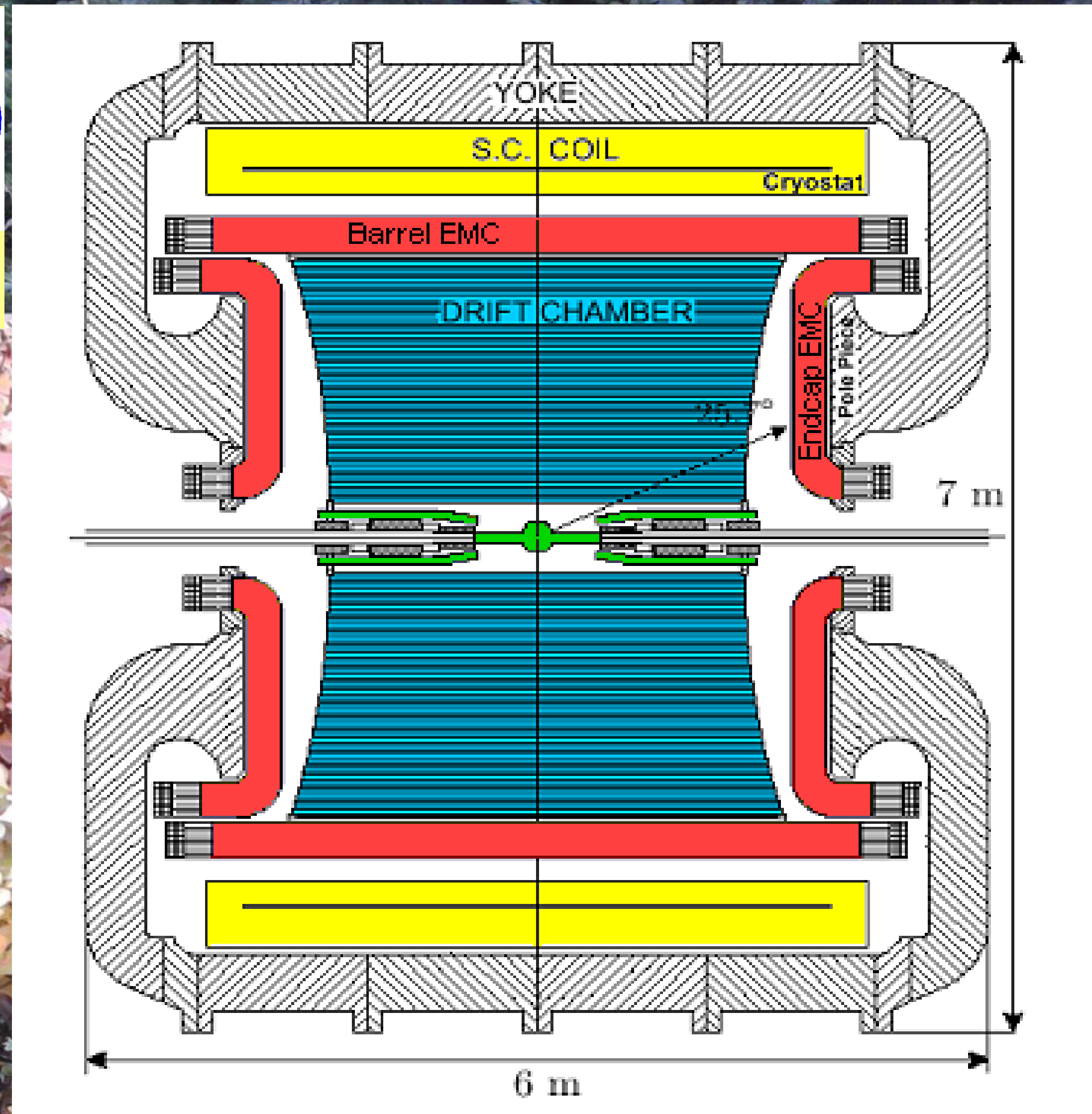


- $e^+e^- \to \phi \quad \sqrt{s} \sim m_\phi = 1019.4$ MeV

BR's for selected ϕ decays	
K^+K^-	49.1%
$K_S K_L$	34.1%
$\rho\pi + \pi^+\pi^-\pi^0$	15.5%
$\eta\,\gamma$	1.3 %
$\eta'\,\gamma$	0.006%

KLOE

K LOng Experiment



KLOE –> KLOE-2

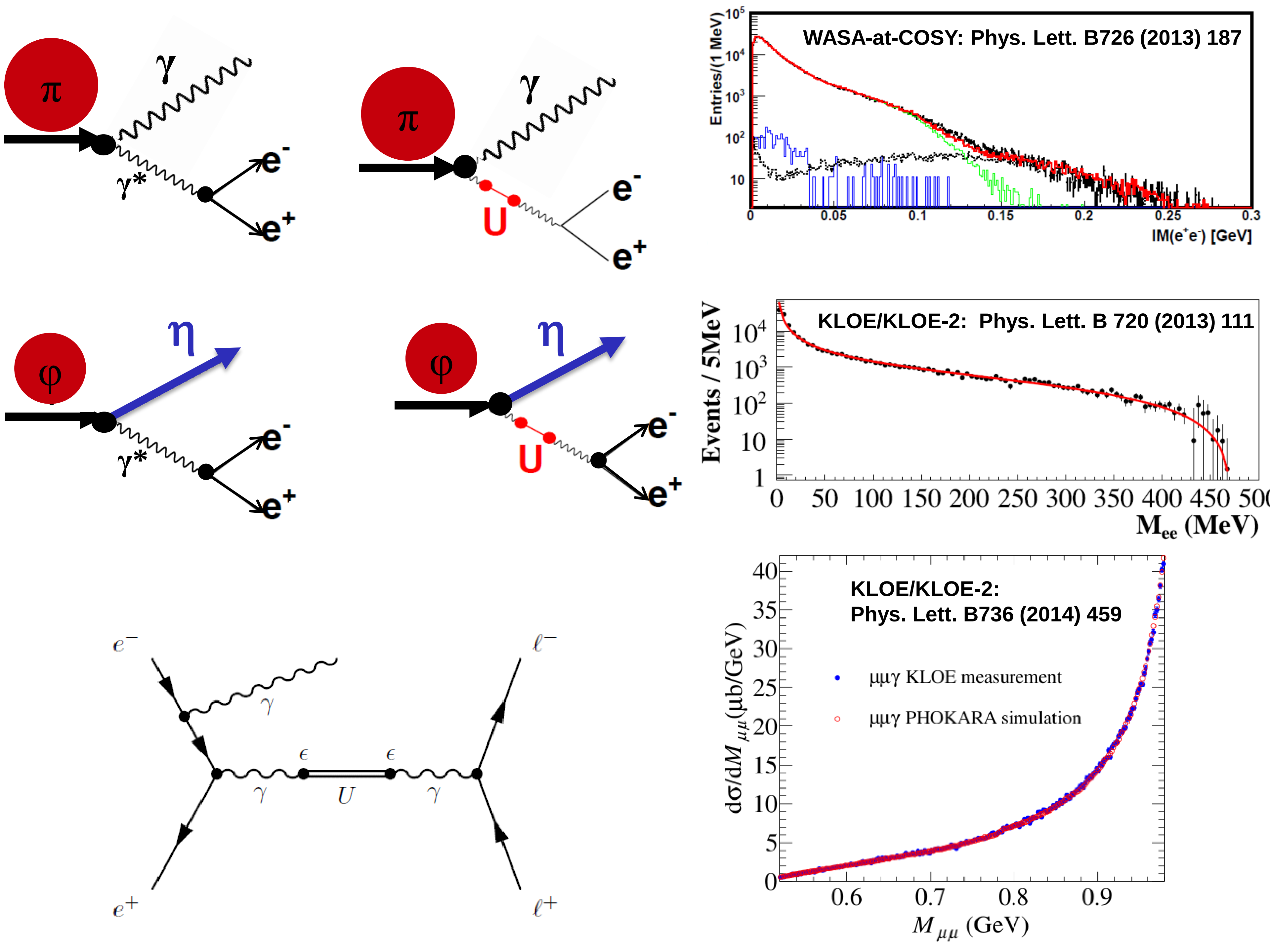
$2.5\ fb^{-1}$ –> $\sim 10\ fb^{-1}$ **(expected)**

$\sim 8 \cdot 10^{9}\ \phi$ –> $\sim 3 \cdot 10^{10}\ \phi$

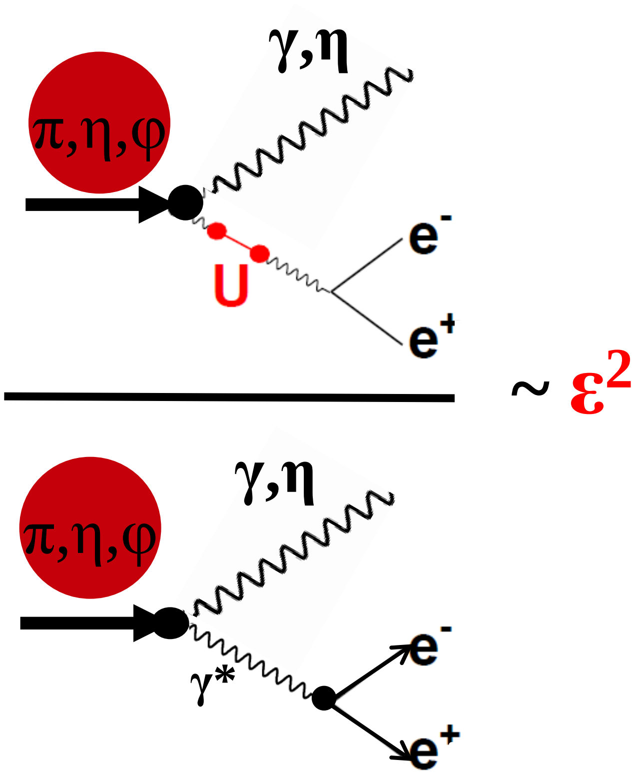
…

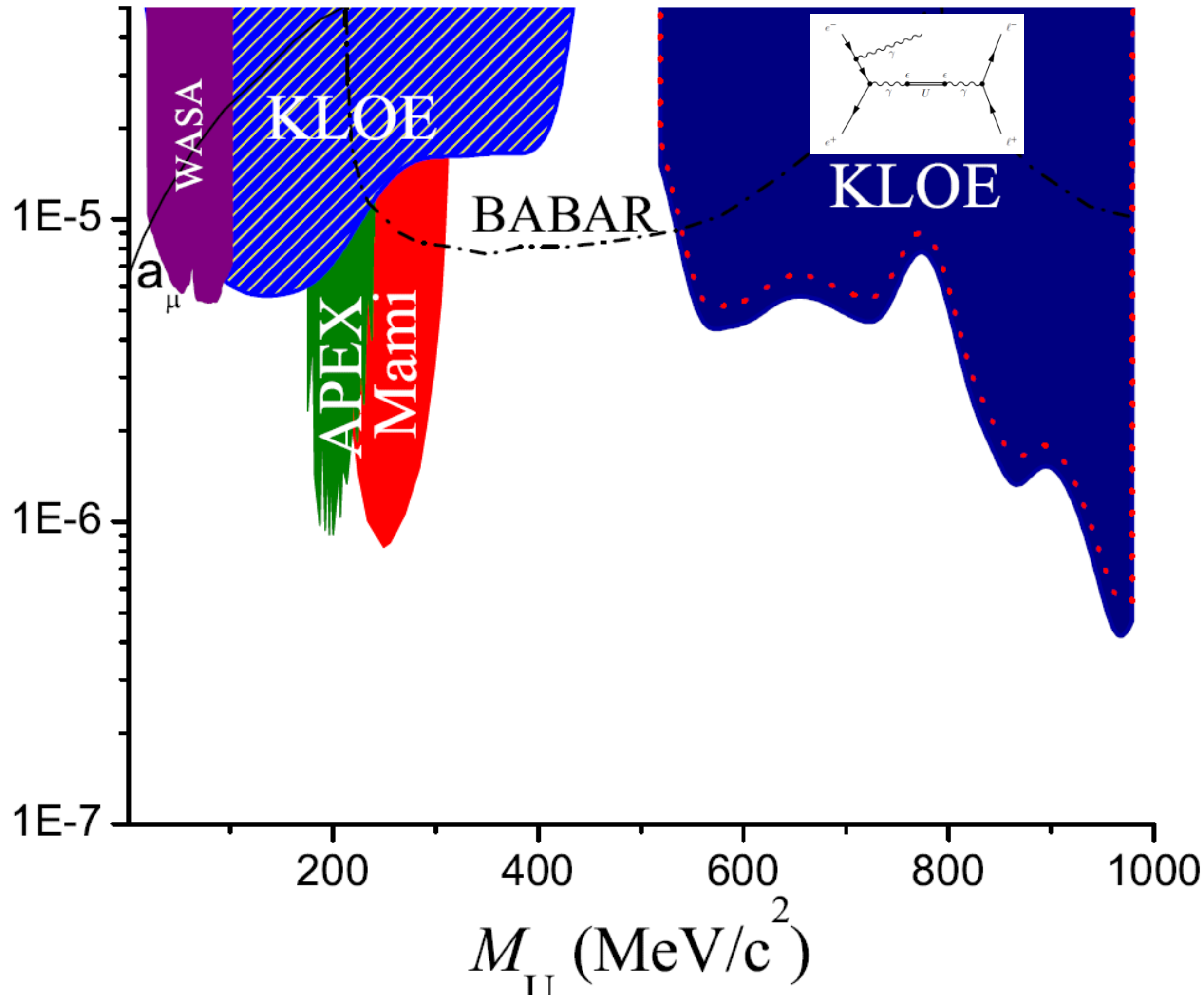
Detector upgrade completed

Experimental camaign in progress ...

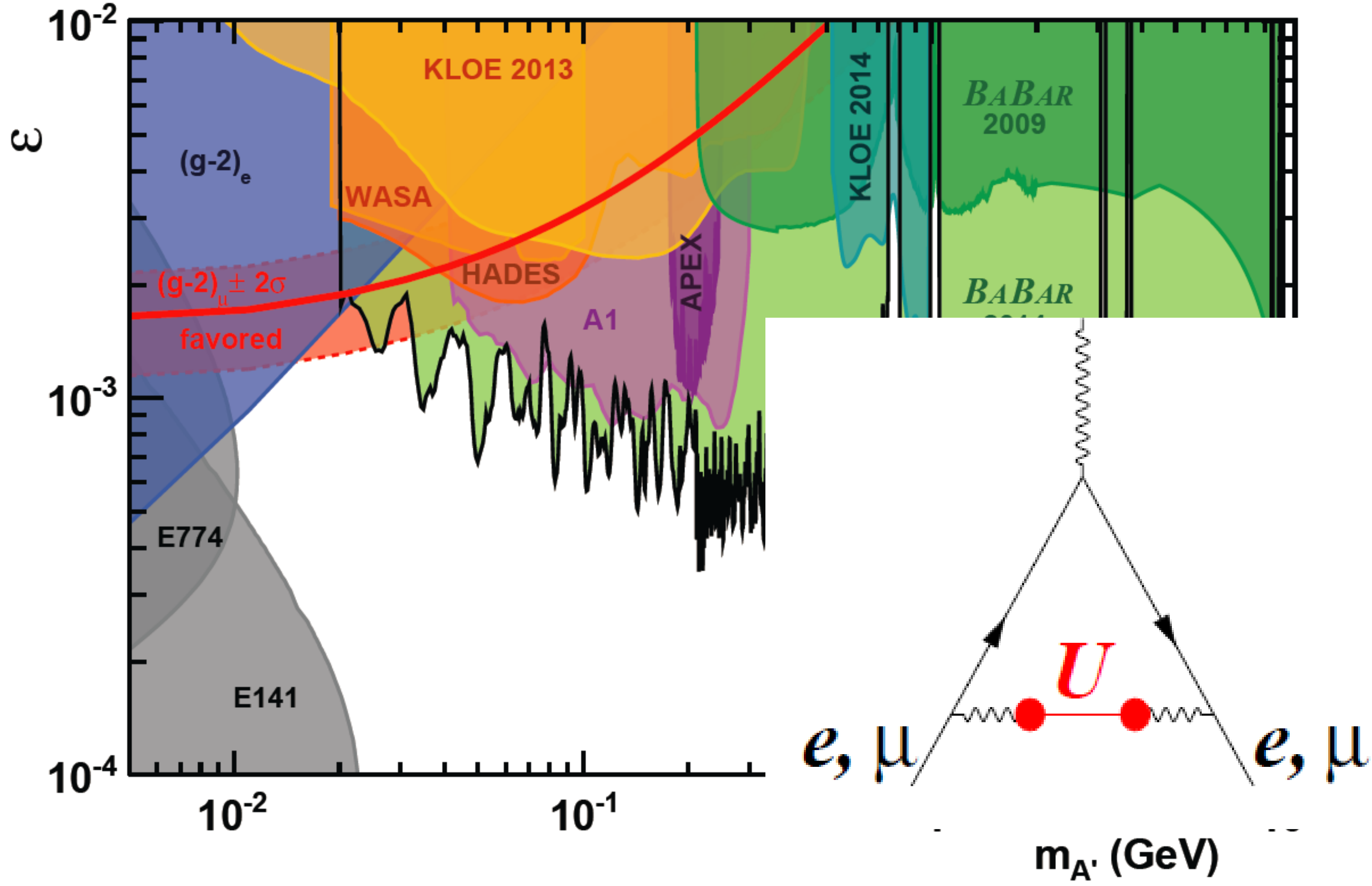


π
γ
γ*
e-
e+
U
φ
η
WASA-at-COSY: Phys. Lett. B726 (2013) 187
Entries/(1 MeV)
IM(e+e-) [GeV]
KLOE/KLOE-2: Phys. Lett. B 720 (2013) 111
Events / 5MeV
M_ee (MeV)
KLOE/KLOE-2:
Phys. Lett. B736 (2014) 459
μμγ KLOE measurement
μμγ PHOKARA simulation
dσ/dM_μμ(μb/GeV)
M_μμ (GeV)
ε
ℓ-
ℓ+

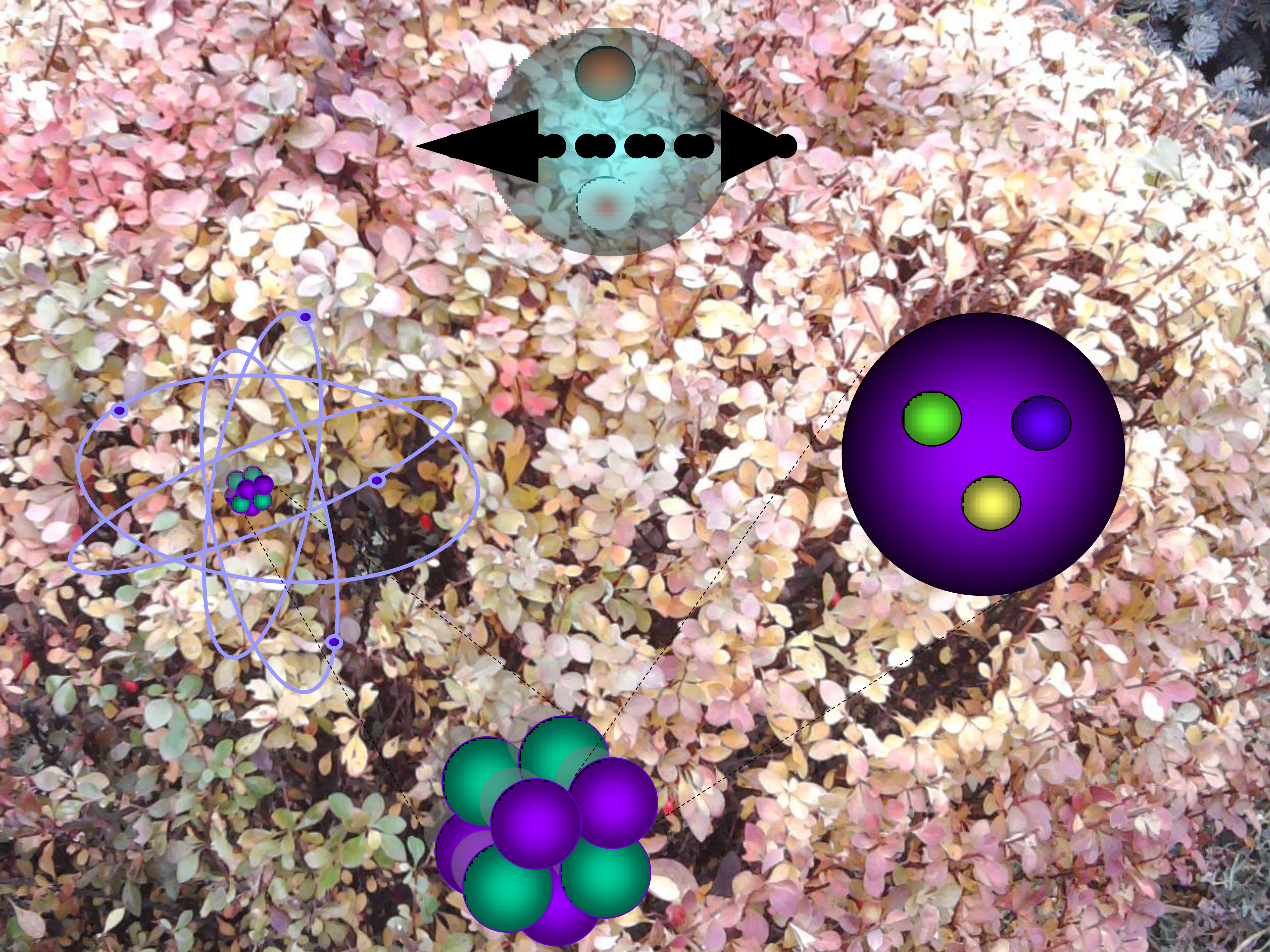


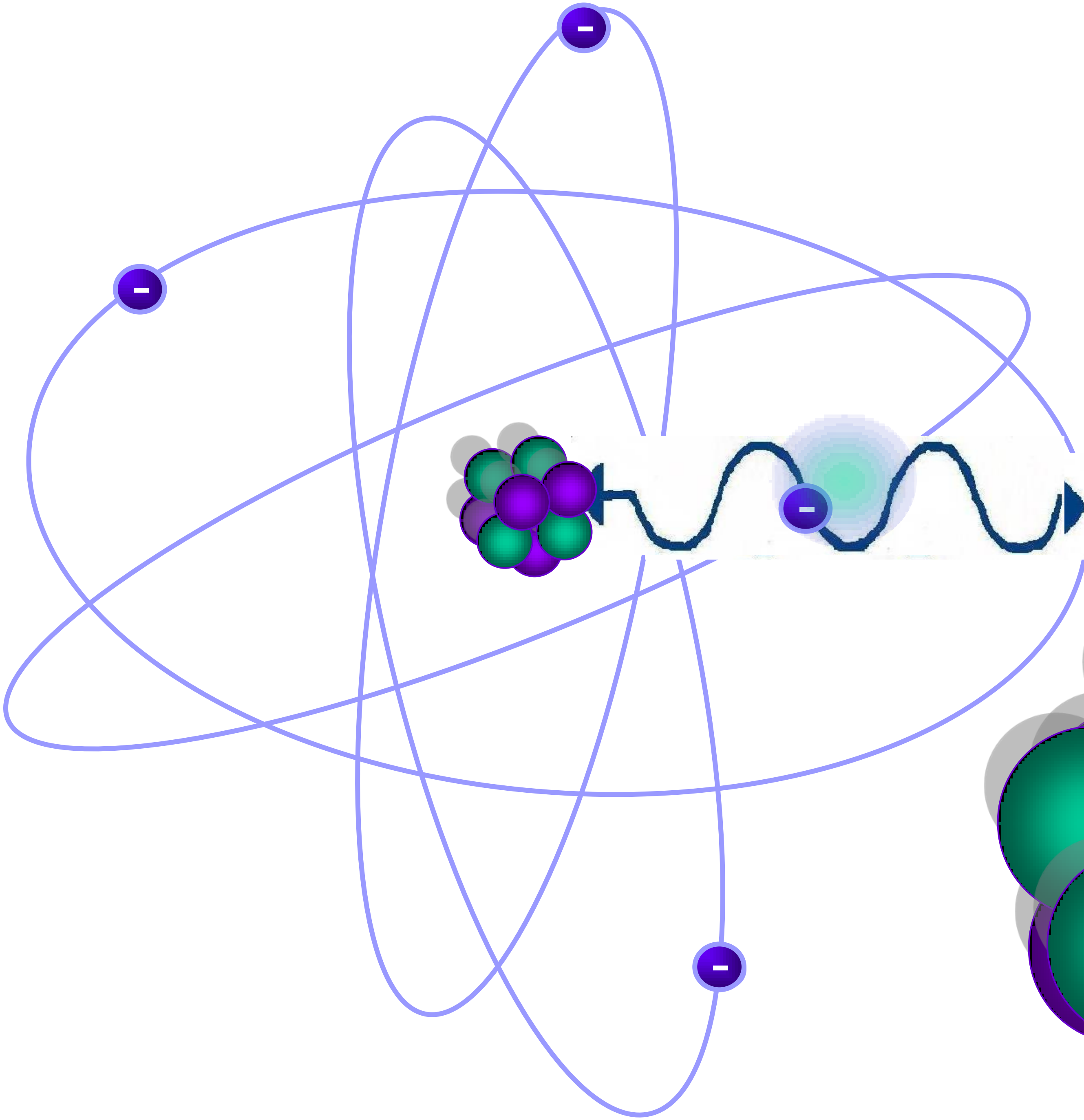


APEX: S. Abrahamyan et al., Phys. Rev. Lett. 107 (2011) 191804
BABAR: B. Aubert et al., Phys. Rev. Lett. 103 (2009) 081803
KLOE/KLOE-2: F. Archilli et al., Phys. Lett. B 720 (2013) 111
KLOE/KLOE-2: D. Babusci et al., Phys.Lett B 706 (2012) 251
MAMI: M. Merkel et al., Phys. Rev. Lett. 106 (2011) 251802
WASA-at-COSY: P. Adlarson et al., Phys. Lett. B 726 (2013) 187
KLOE/KLOE-2: D. Babusci et al., Phys.Lett. B736 (2014) 459-464

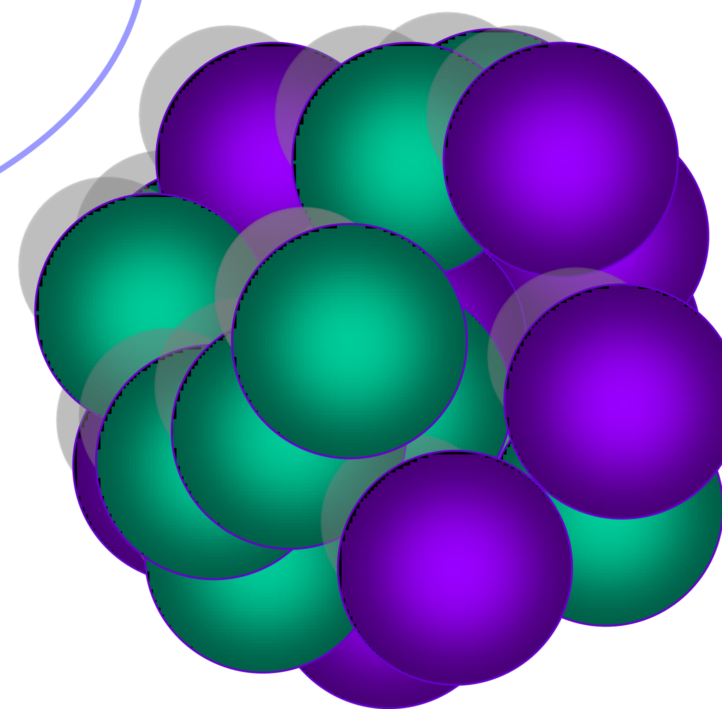


BABAR: J.P. Lees et al., Phys.Rev.Lett. 113 (2014) 20, 201801
HADES: G. Agakishiev et al., Phys.Lett. B731 (2014) 265-271





$$^{18}F \longrightarrow {}^{18}O + e^{+} + \nu_e$$

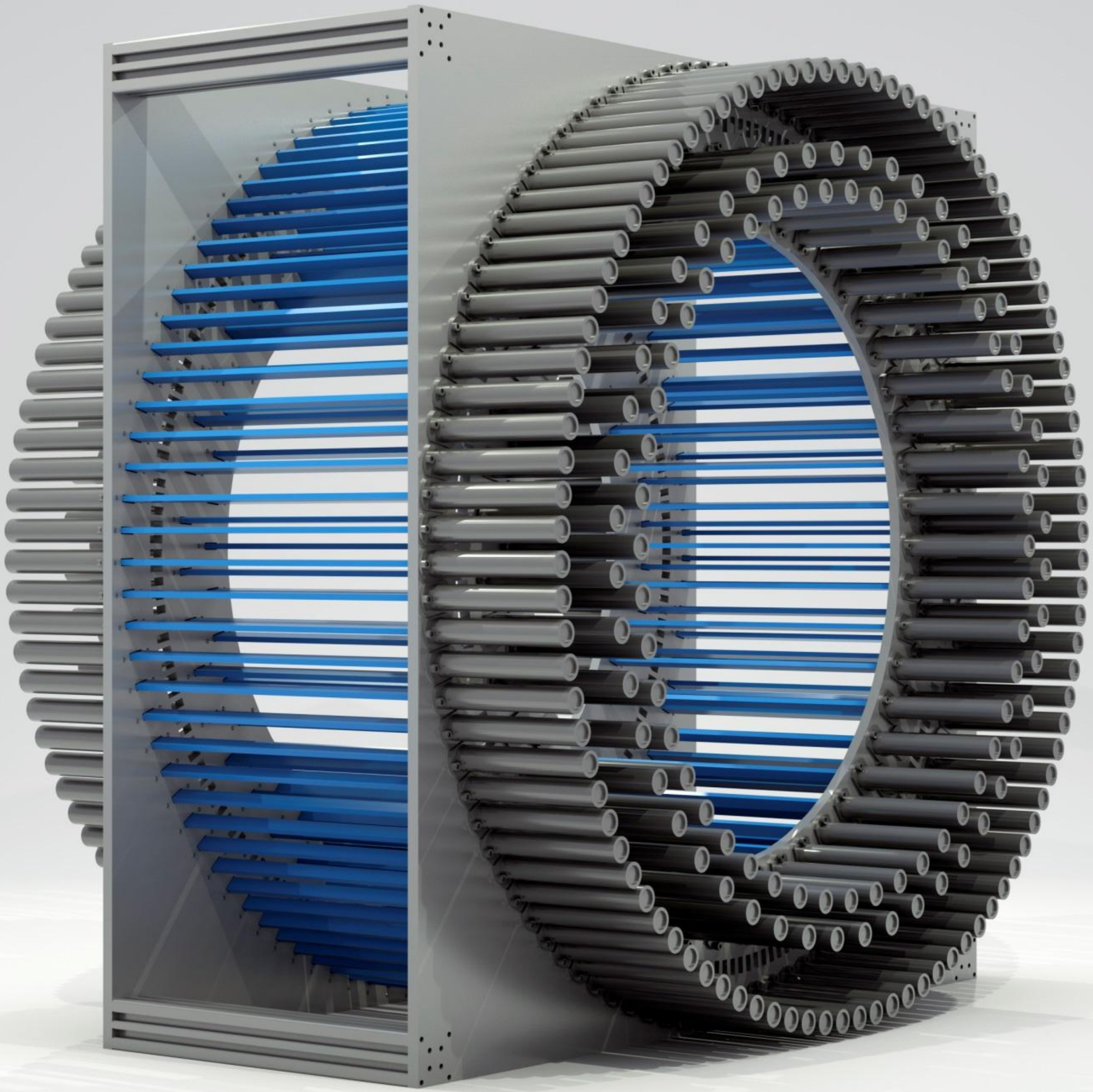


fizyka, bio-fizyka, medycyna

- materia -- anty-materia
- ciemny foton
- Jagielloński PET
- symetrie dyskretne
- nano-struktura komórek

Jagiellonian **PET**

Jagiellonian PET



kryształy → plastiki

Zupełnie nowe podejście nieakceptowane przez Ekspertów !

KAPITAŁ LUDZKI
NARODOWA STRATEGIA SPÓJNOŚCI

Projekt współfinansowany przez Unię Europejską
w ramach Programu Operacyjnego Kapitał Ludzki

UNIA EUROPEJSKA
EUROPEJSKI
FUNDUSZ SPOŁECZNY

numer umowy: Umowa nr CITTRU/061023/01/10/2009
płatne ze środków: budżetu projektu Kompas innowacji (PSP:S/FS0/0023)
jednostka organizacyjna: CITTRU

Warszawa, dnia 17 listopada 2009 roku.

P. M., Patent (2014) Nr EP2454612B1, WO2011008119, EP2454611, WO2011008118.

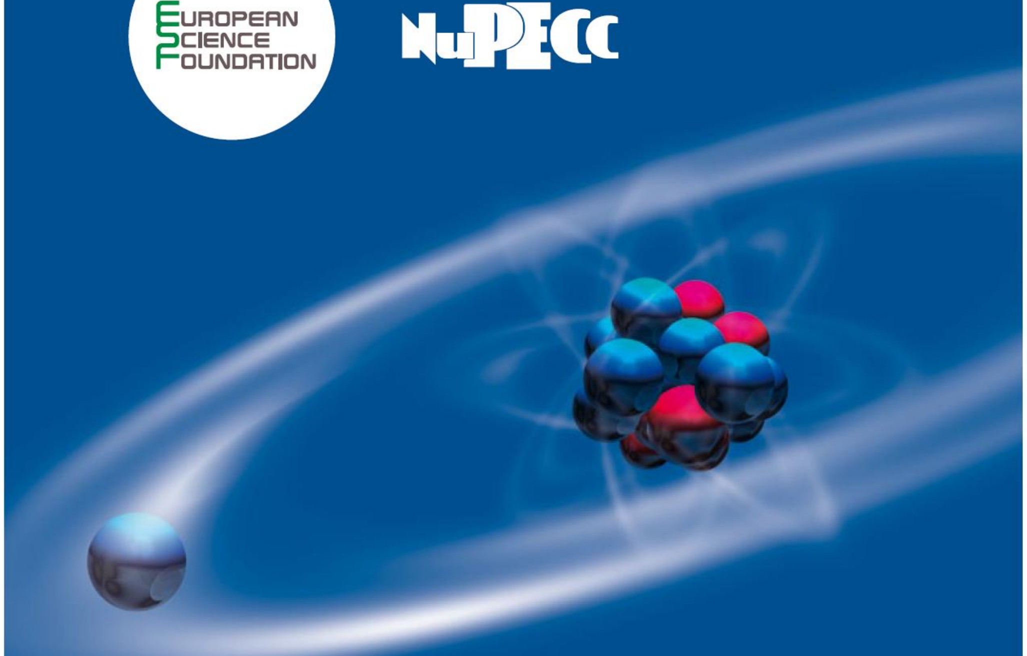
Recenzja wniosku patentowego nr 9534/09

„Urządzenie matrycowe i sposób do wyznaczania miejsca i czasu reakcji kwantów gamma oraz zastosowanie urządzenia do wyznaczania miejsca i czasu reakcji kwantów gamma w emisyjnej tomografii pozytonowej"

Kierując się obecnym stanem wiedzy, zarówno z zakresu dostępnych technologii, jaki i podstaw fizyki uważam, że proponowane rozwiązanie nie nadaje się do zastosowania w praktyce. Przedłożony wniosek przedstawia ogólną definicję tomografii pozytonowo emisyjnej, natomiast w dalszym jego części proponuje rozwiązania, które świadczą o niezrozumieniu zasady działania układu detekcyjnego będącego fizyczną podstawą dyskutowanej metody obrazowania, czyli detekcji kwantów anihilacji gamma o energii 511 keV.

EUROPEAN SCIENCE FOUNDATION

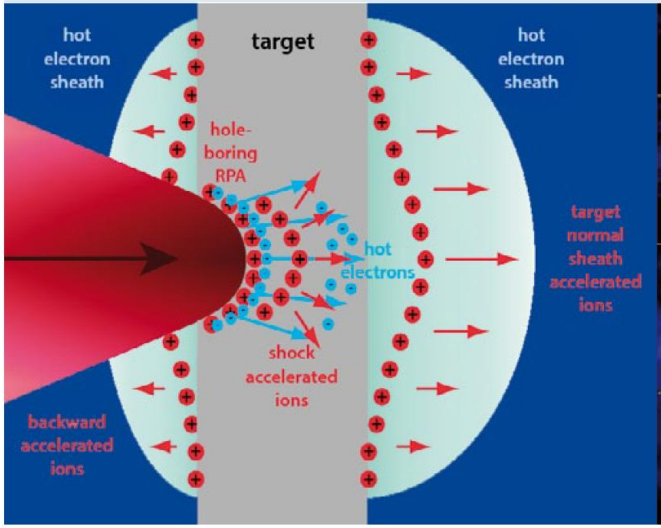
NuPECC

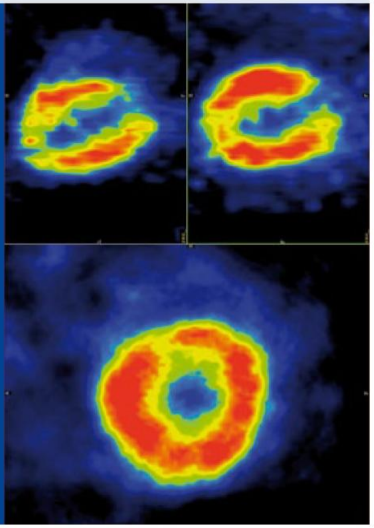


Printed April 2014

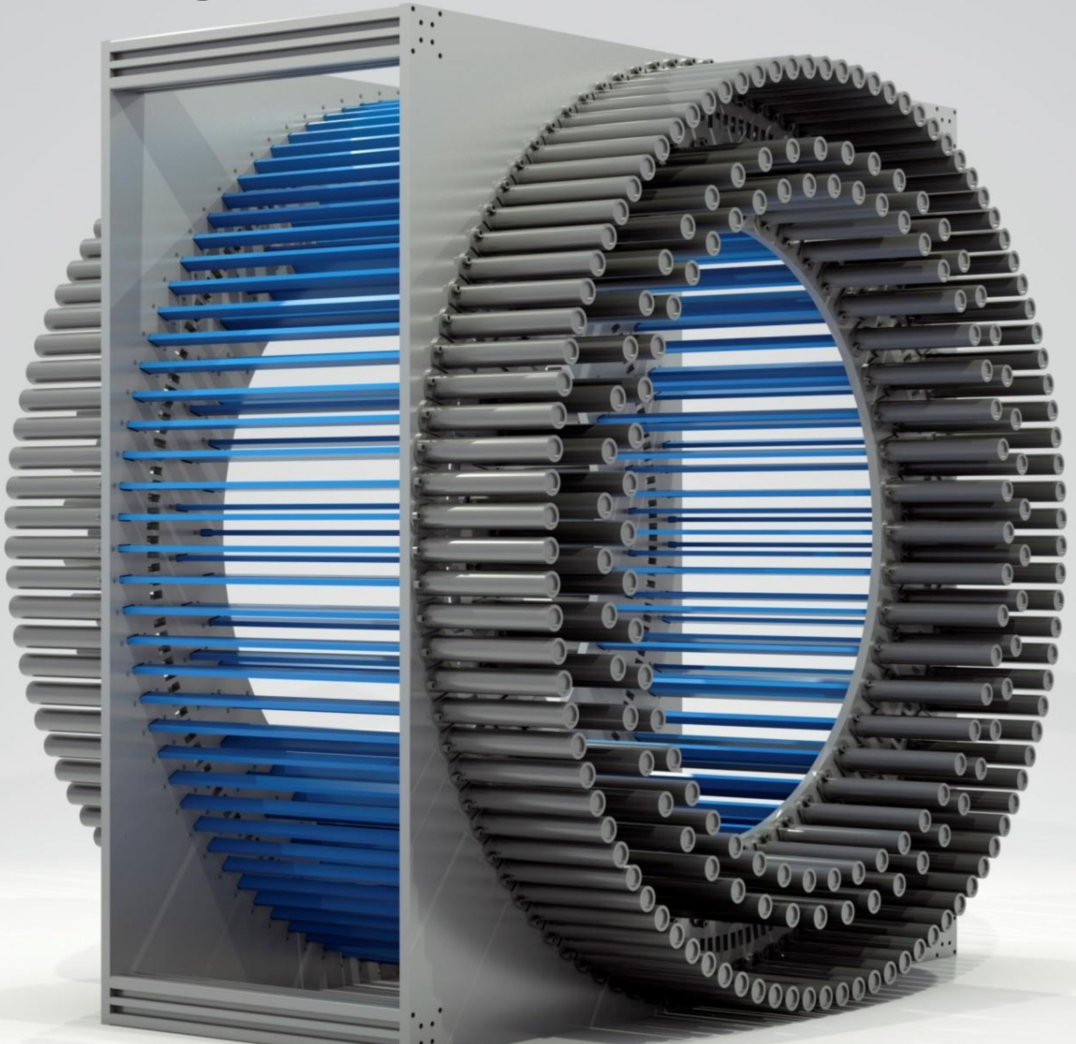
Nuclear Physics European Collaboration Committee (NuPECC)

Nuclear Physics for Medicine





Jagiellonian PET



kryształy
→ plastiki

P. M. et al., Radioteraphy and Oncology 110 (2014) S69
L. Raczyński et al., Nucl. Instrum. Meth. A764 (2014) 186
P. M. et al., Nucl. Instrum. Meth. A764 (2014) 317
P. M. et al., Nucl. Instrum. Meth. A775 (2015) 54
L. Raczyński et al., Nucl. Instrum. Meth. A786 (2015) 105
~30 articles and 12 International patent applications

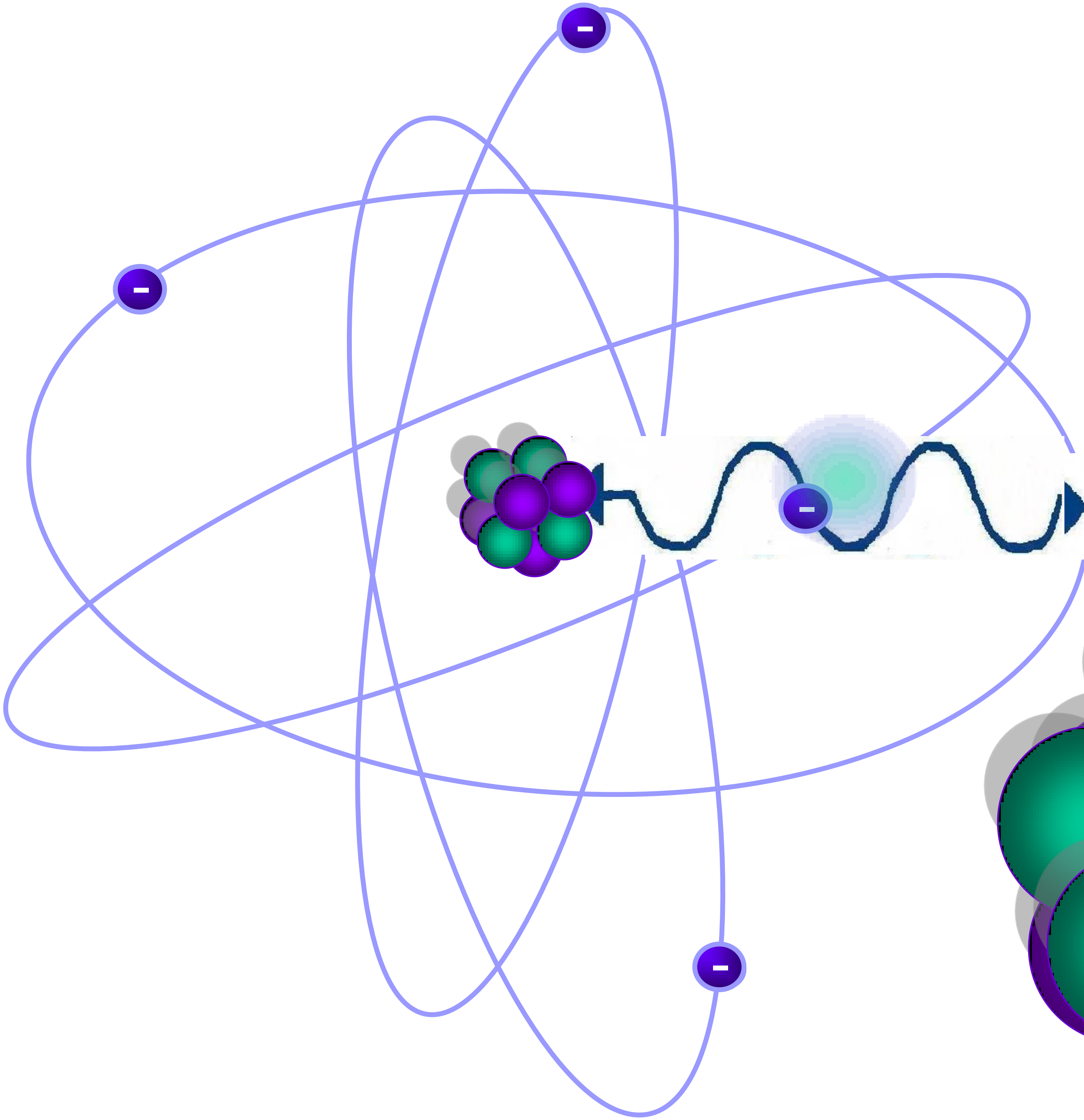
J-PET

W komórkach nowotworowych
glikoliza zwiekszona jest
20 do 30 razy
-zjawisko Warburga -

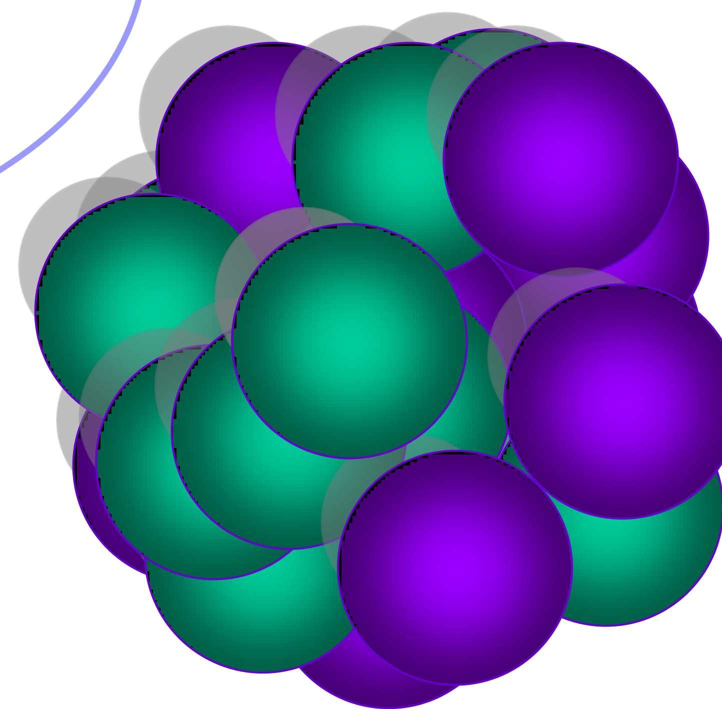
Mechaniz pułapki molekularnej
powoduje, że fosforan glukozy
gromadzi się w komórkach

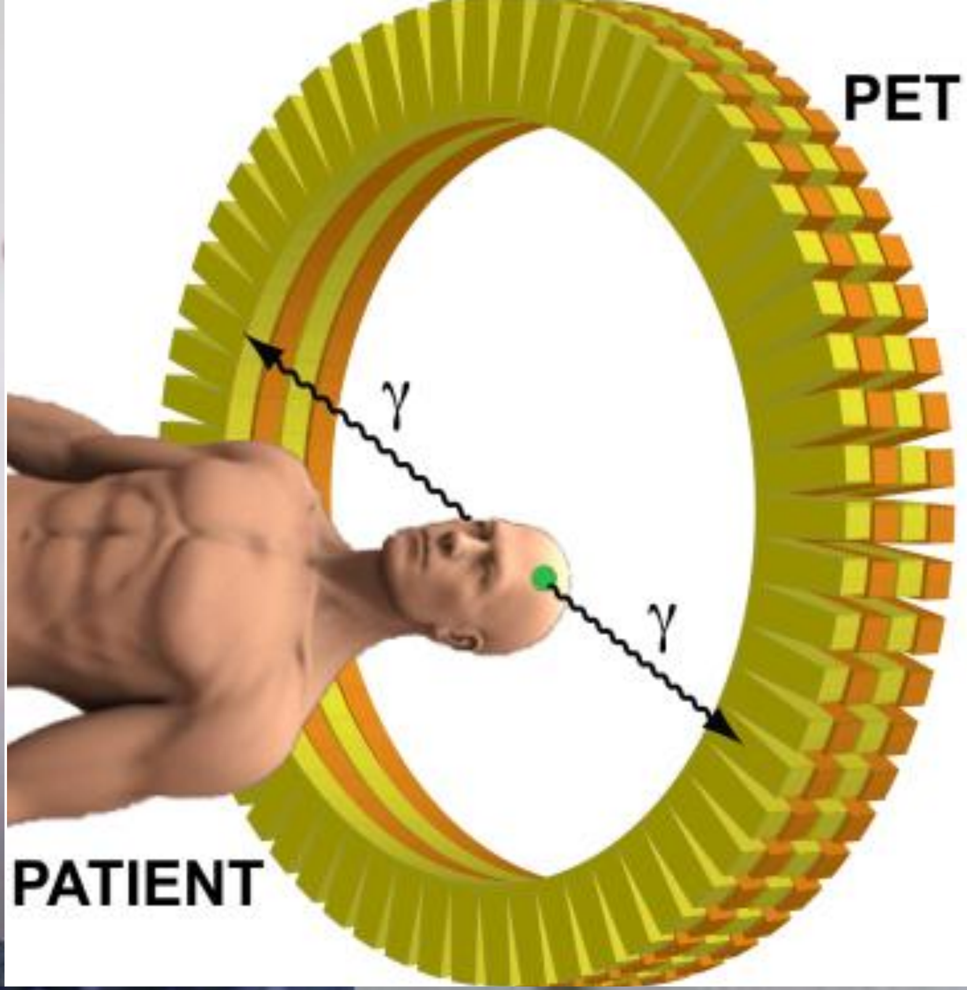
CUKIER RADIOAKTYWNY

Fluoro–deoksy-glukoza
(F-18 FDG)



$$^{18}F \longrightarrow {}^{18}O + e^{+} + \nu_e$$



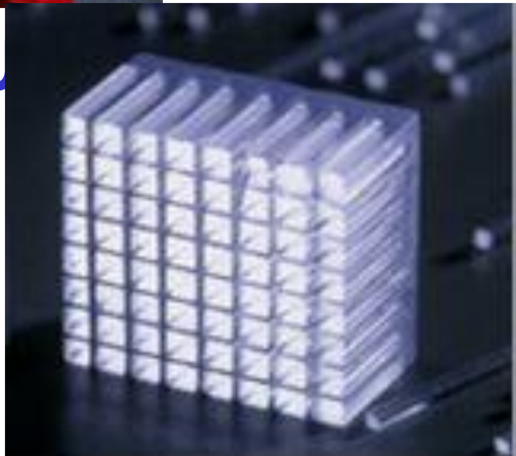


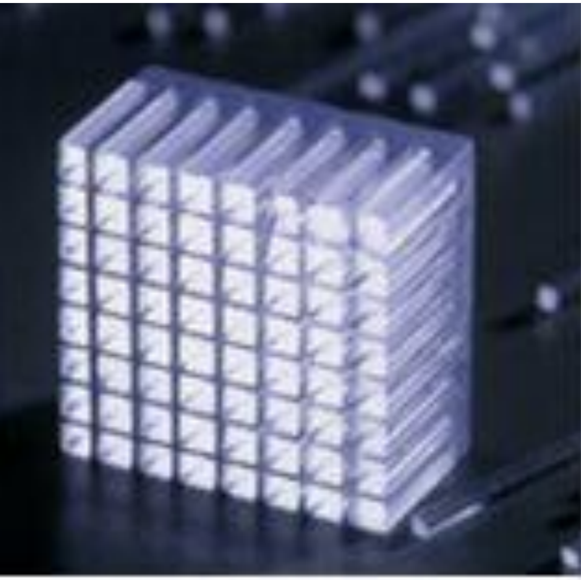
RADIOAKTYWNY CU

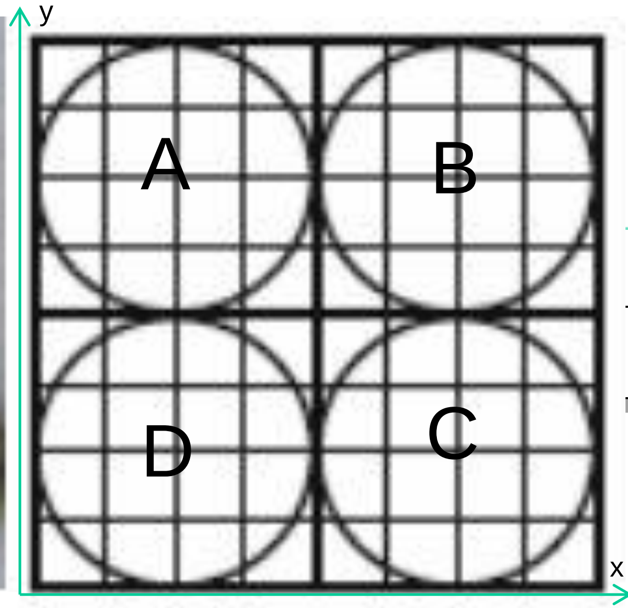
Fluoro–deoksy-glukoza (F-18 FDG)

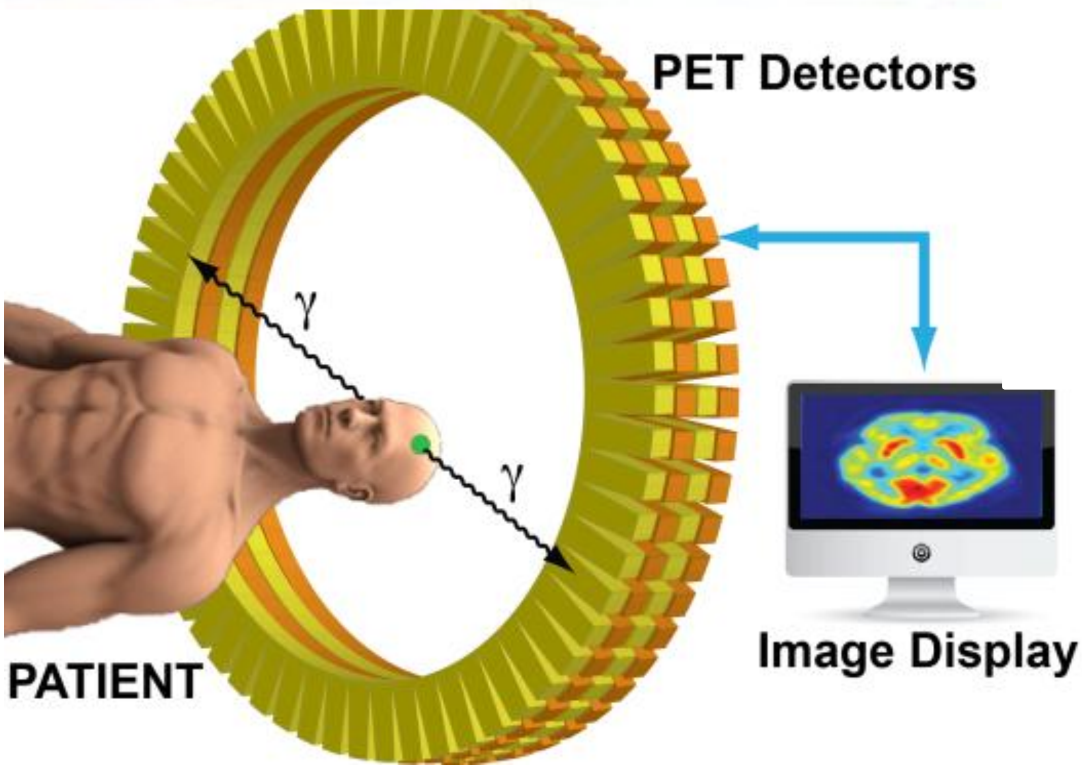
~200 000 000

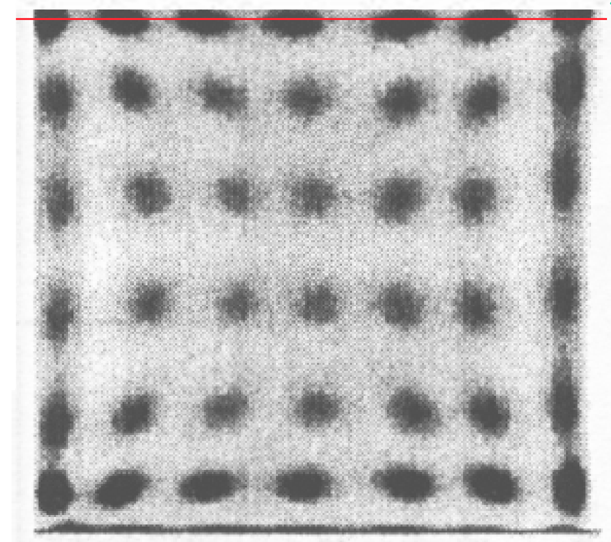
kwantów gamma na sekunde





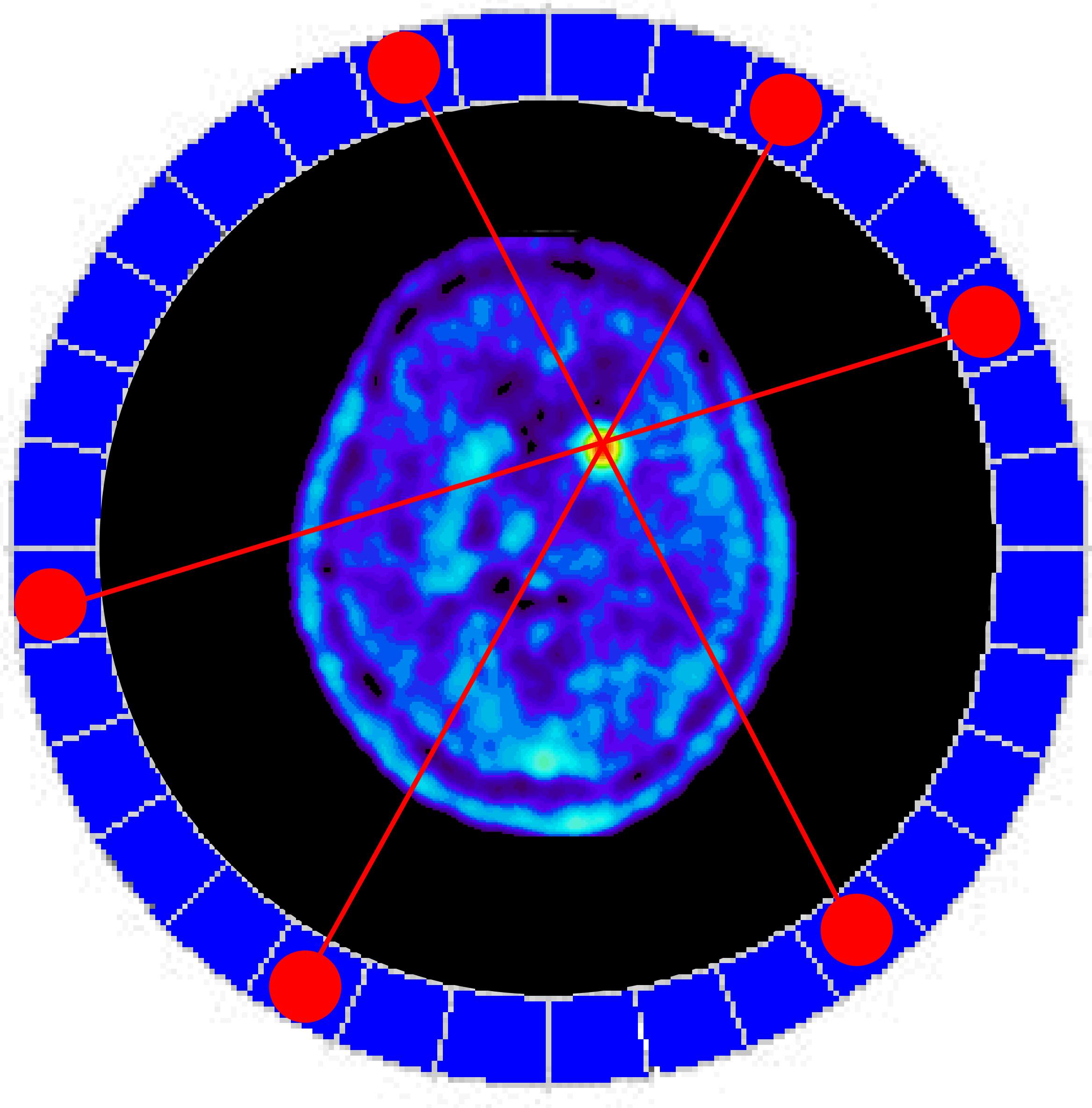


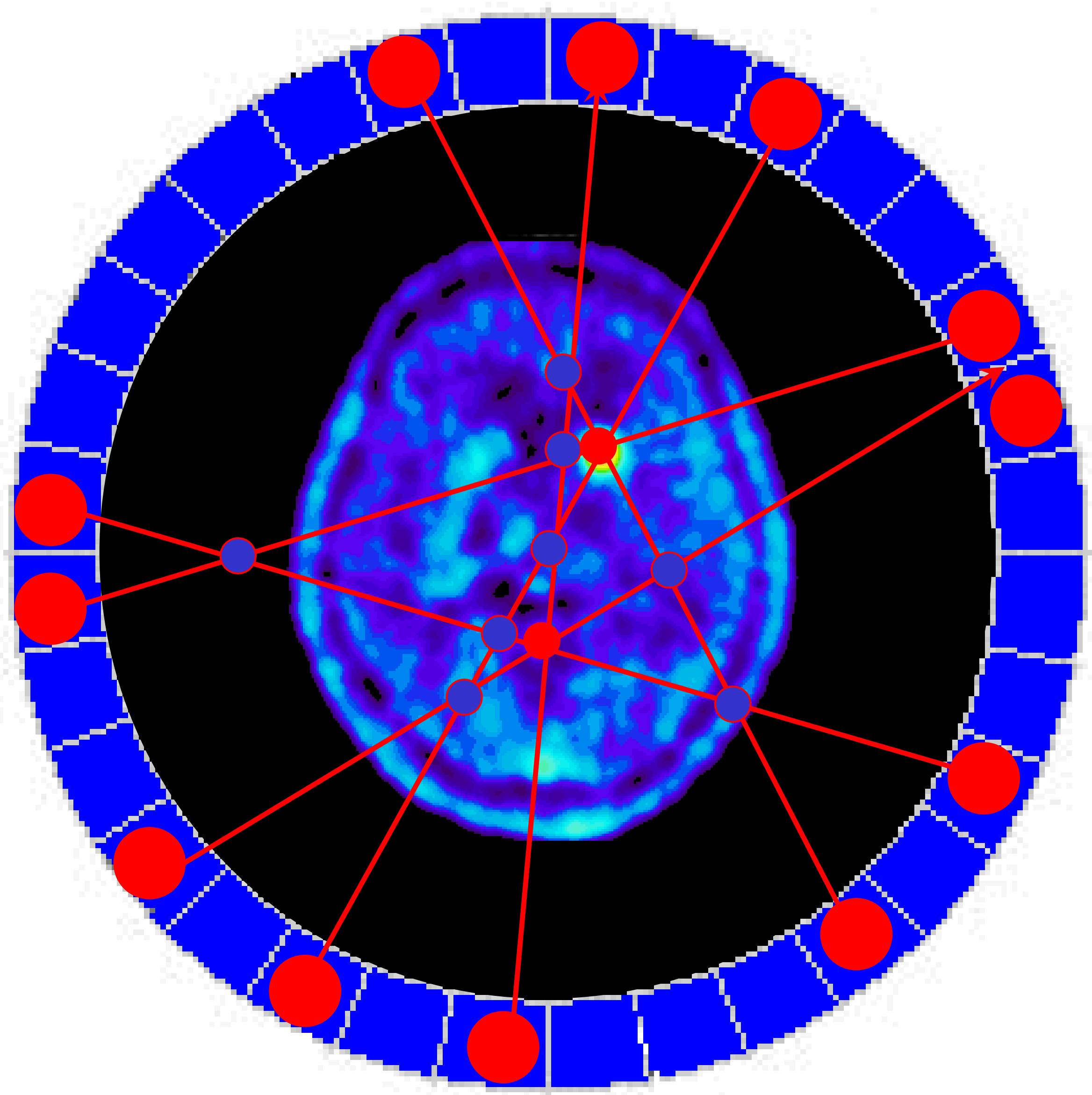


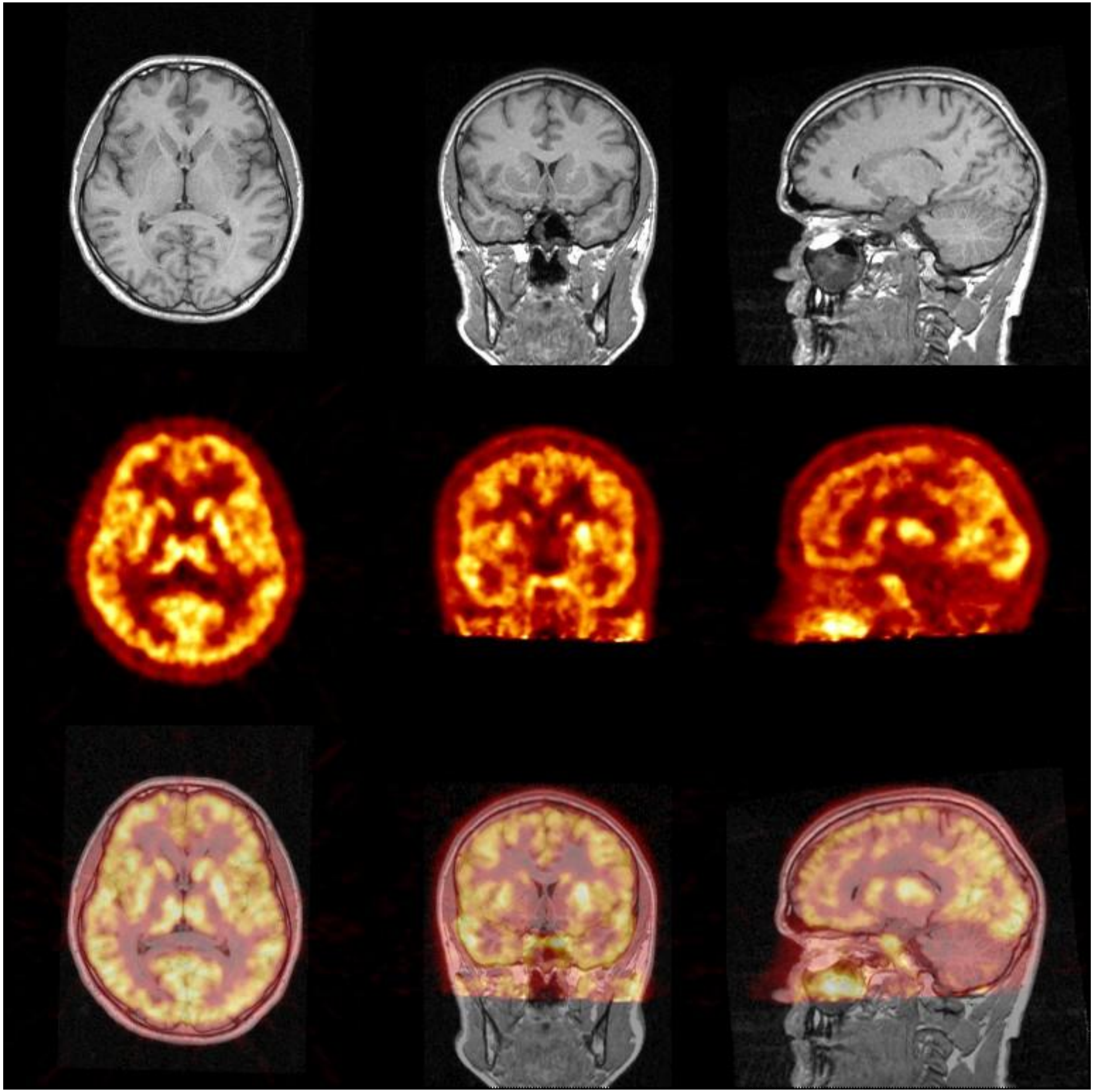


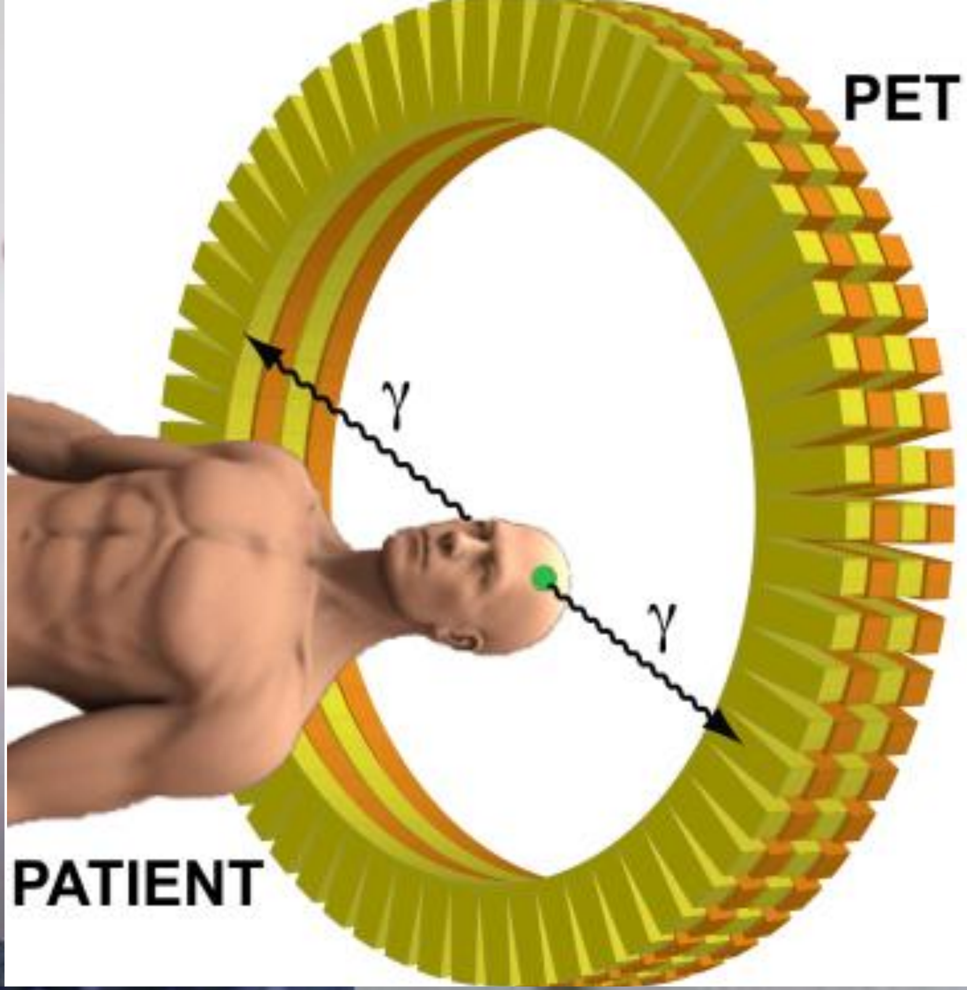
$$X = \frac{(B+C)-(A+D)}{A+B+C+D},$$

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







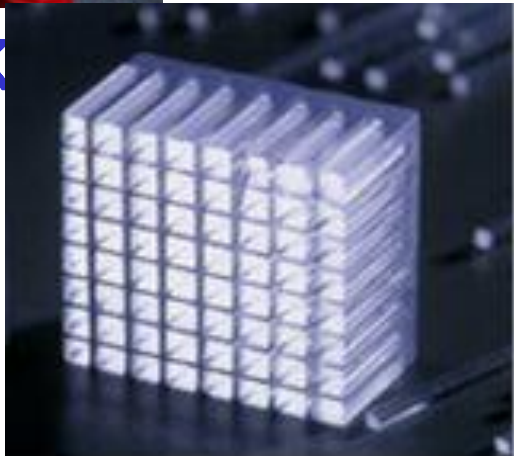


RADIOAKTYWNY CUK

Fluoro–deoksy-glukoza (F-18 FDG)

~200 000 000

kwantów gamma na sekunde



Type: LSO / LYSO / BGO / scyntylatory polimerowe

Price per cm^3: 86 / 86 / 35 / 1

Polimery można łatwo produkować o dowolnych rozmiarach i kształtach

PHILIPS → LYSO

SIMENS → LSO

GE Healthcare → BGO

Dlaczego scyntylatory plastikowe nie były rozważane jako materiał do budowy tomografów PET ?

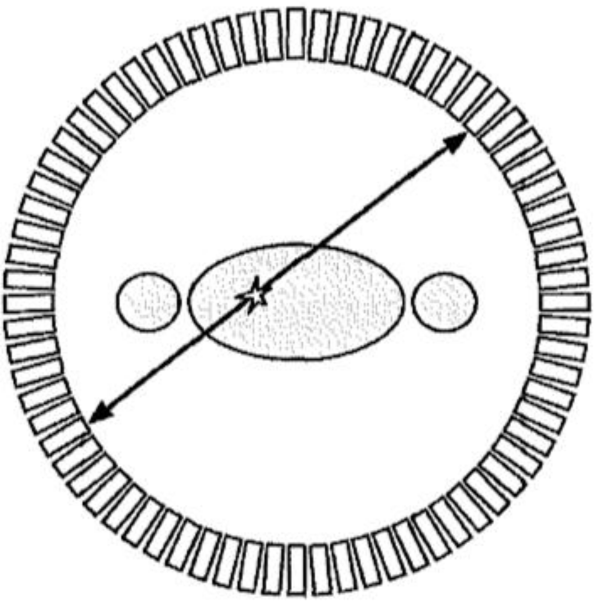
dla 2.5 cm warstwy wydajność rejestracji zdarzeń plastikowymi scyntylatorami jest

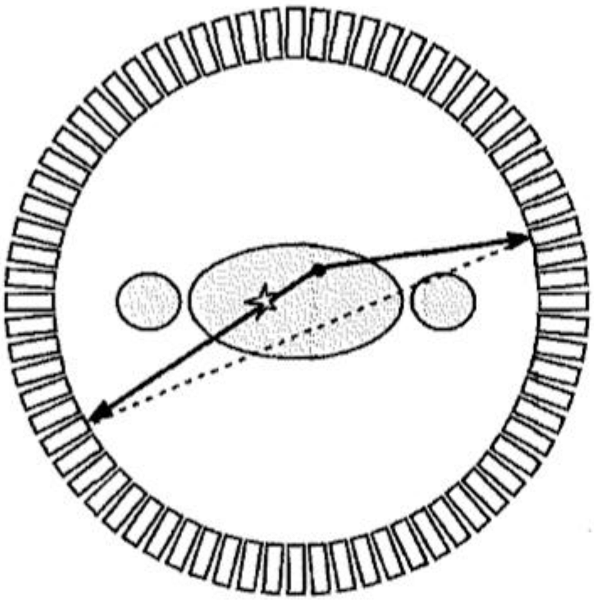
około 20 razy mniejsza w stosunku do kryształów BGO i około 40 razy mniejsza w stosunku do kryształów LSO

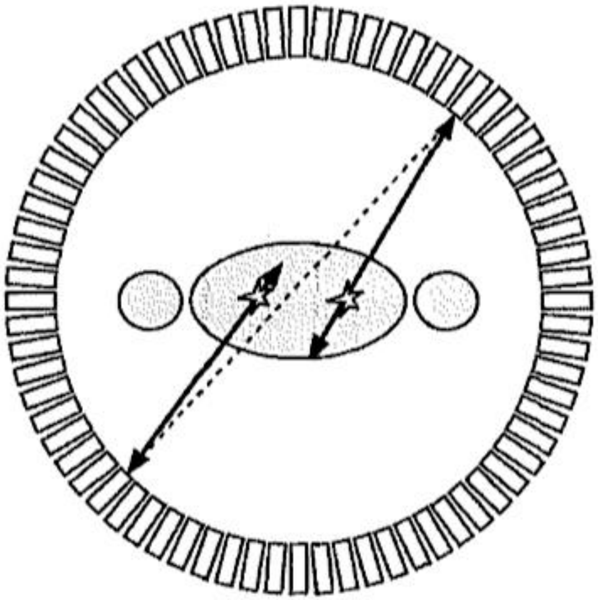
name	type	density [g/cm^3]	decay time [ns]	photons/ MeV	mean free path [cm]
BGO	crystal	7.13	300	6000	1.04
GSO	crystal	6.71	50	10000	1.49
LSO	crystal	7.40	40	29000	1.15
NE102A	polymer	1.032	2.4	10000	10.2
BC404	polymer	1.032	1.8	10000	10.2
RP422	polymer	1.032	1.6	10000	10.2

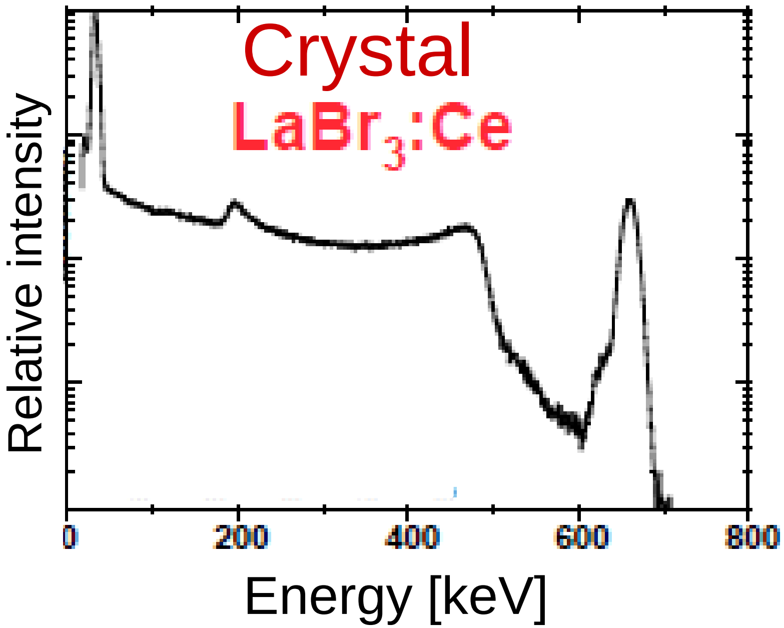
ZDARZENIA

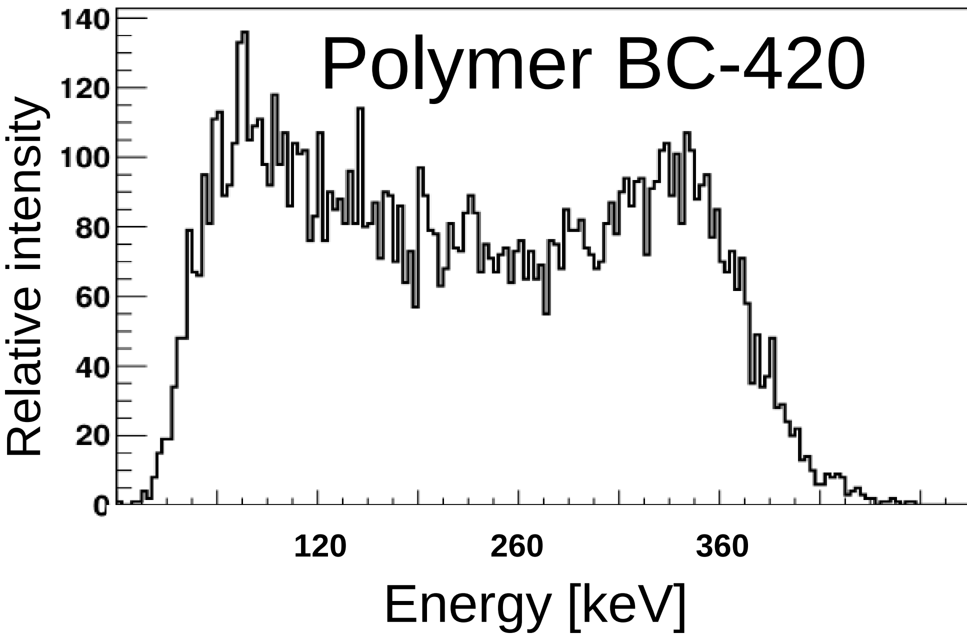
„prawdziwe” „rozproszone” „przypadkowe”









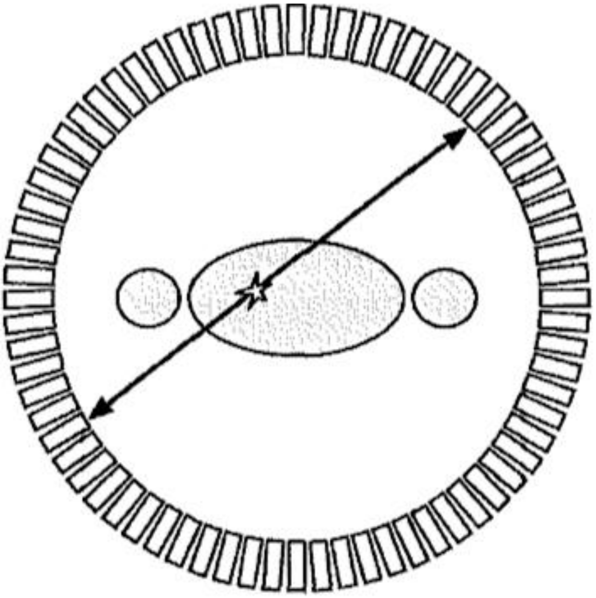


Polimery:
niska wydajność detekcji
oraz
„brak” efektu fotoelektrycznego,

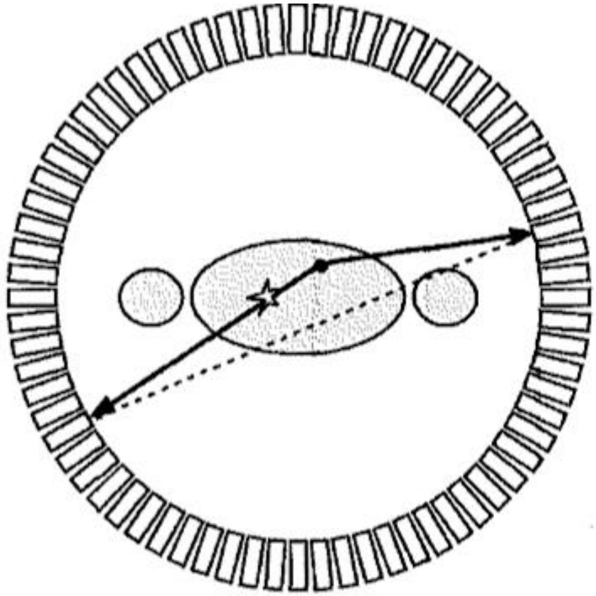
ALE …

EVENTS

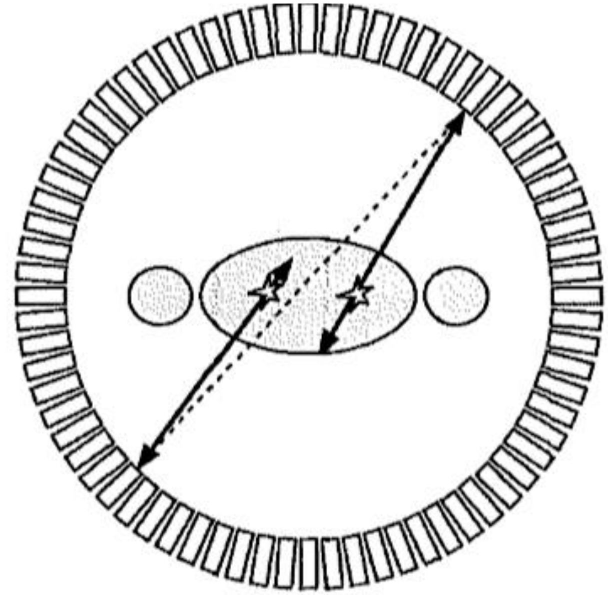
„true”

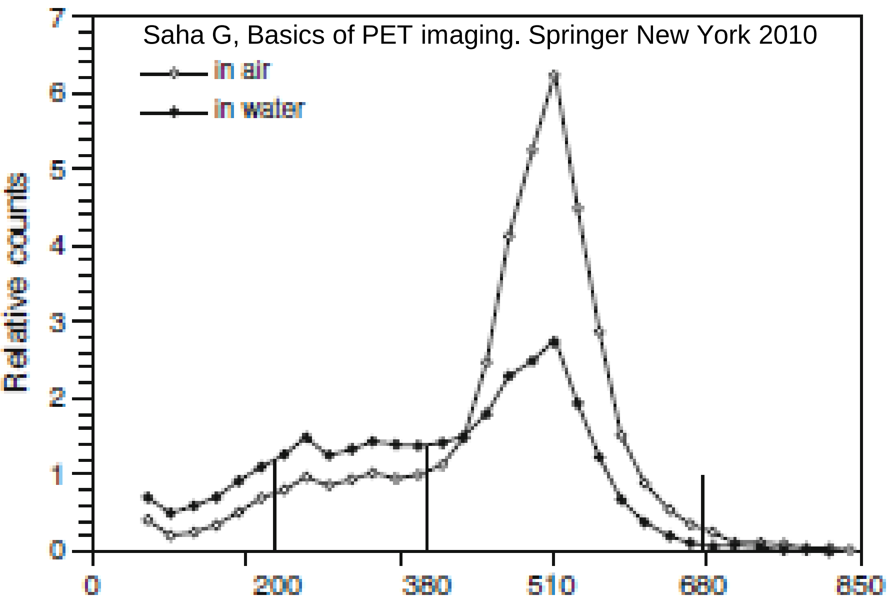


„scattered”

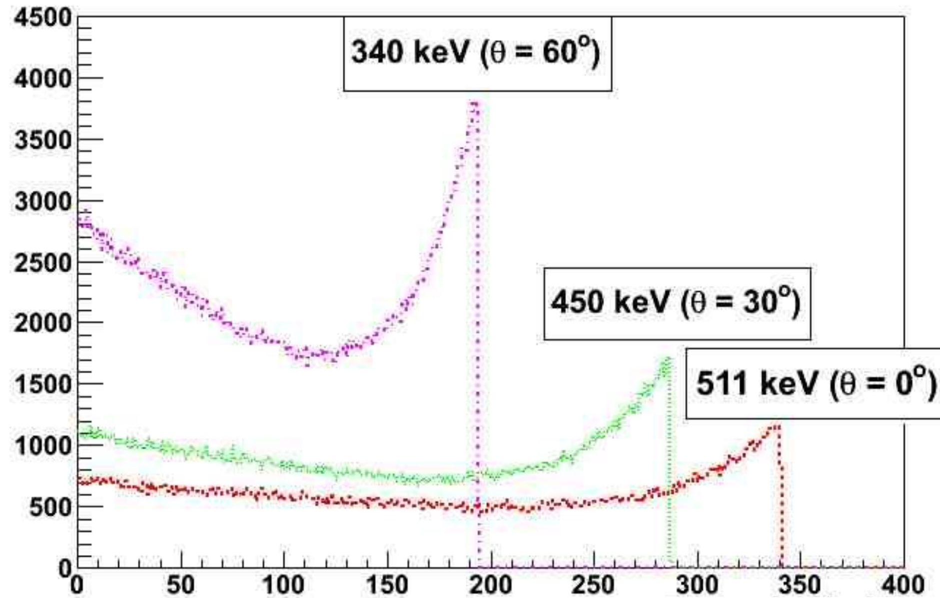


accidental





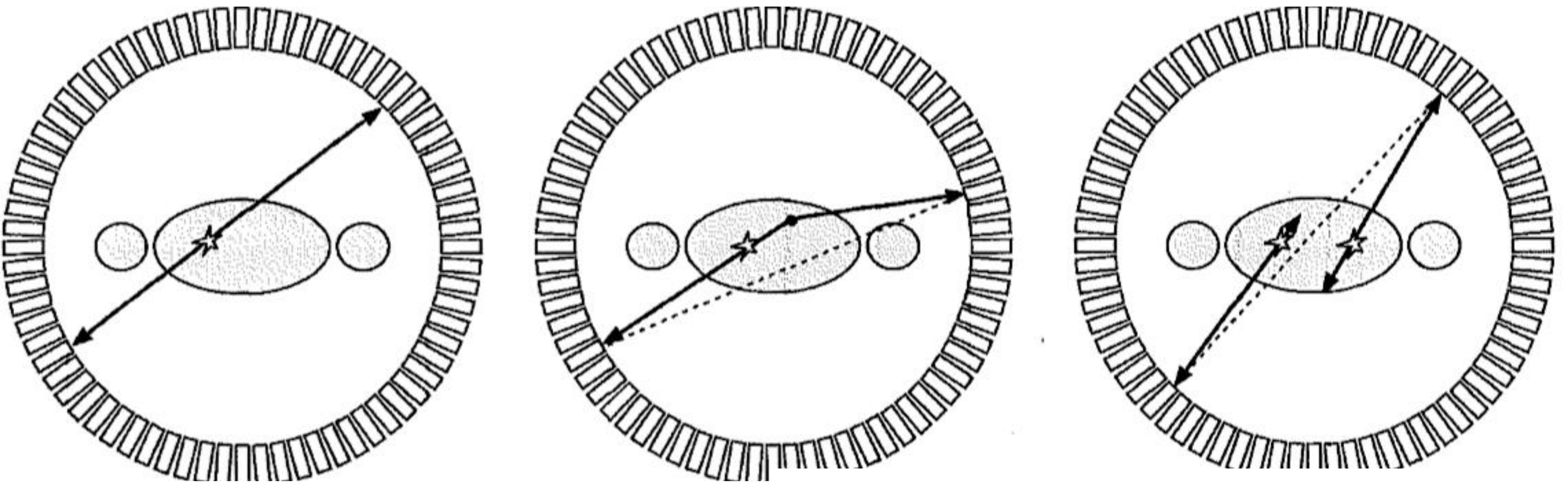
Energy [keV]

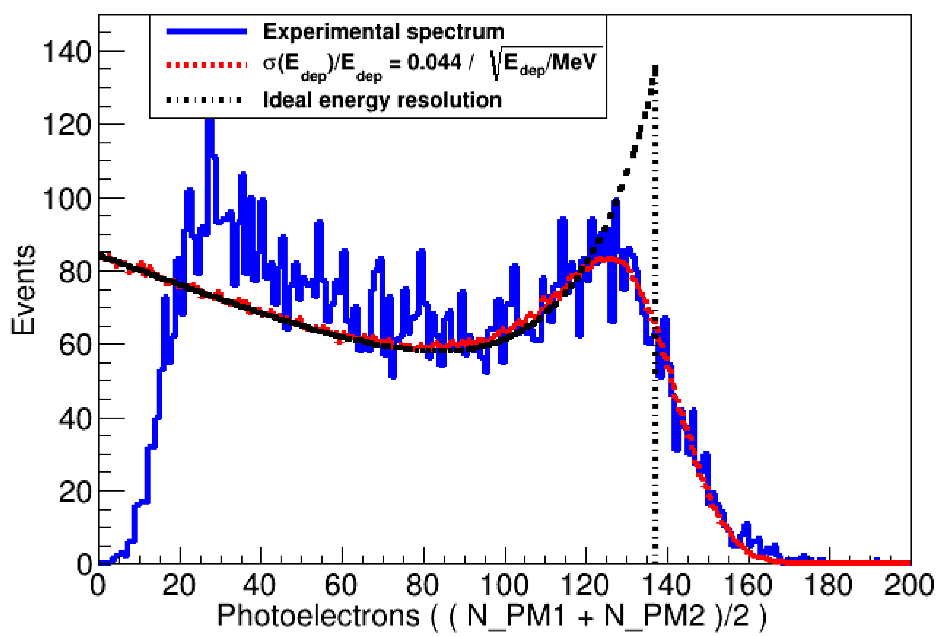


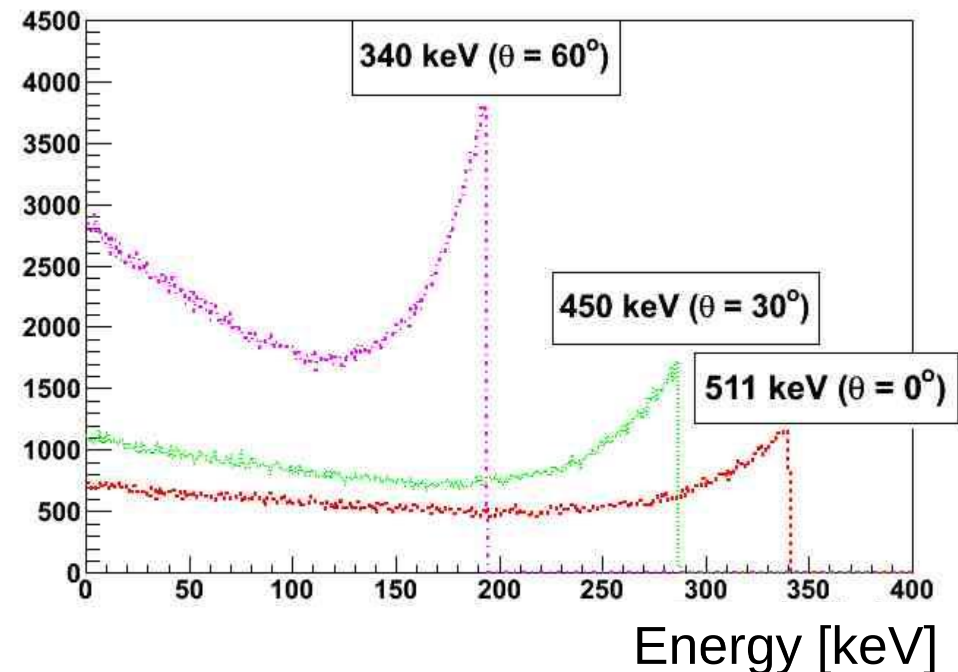
Energy [keV]

EVENTS

„true” „scattered” accidental

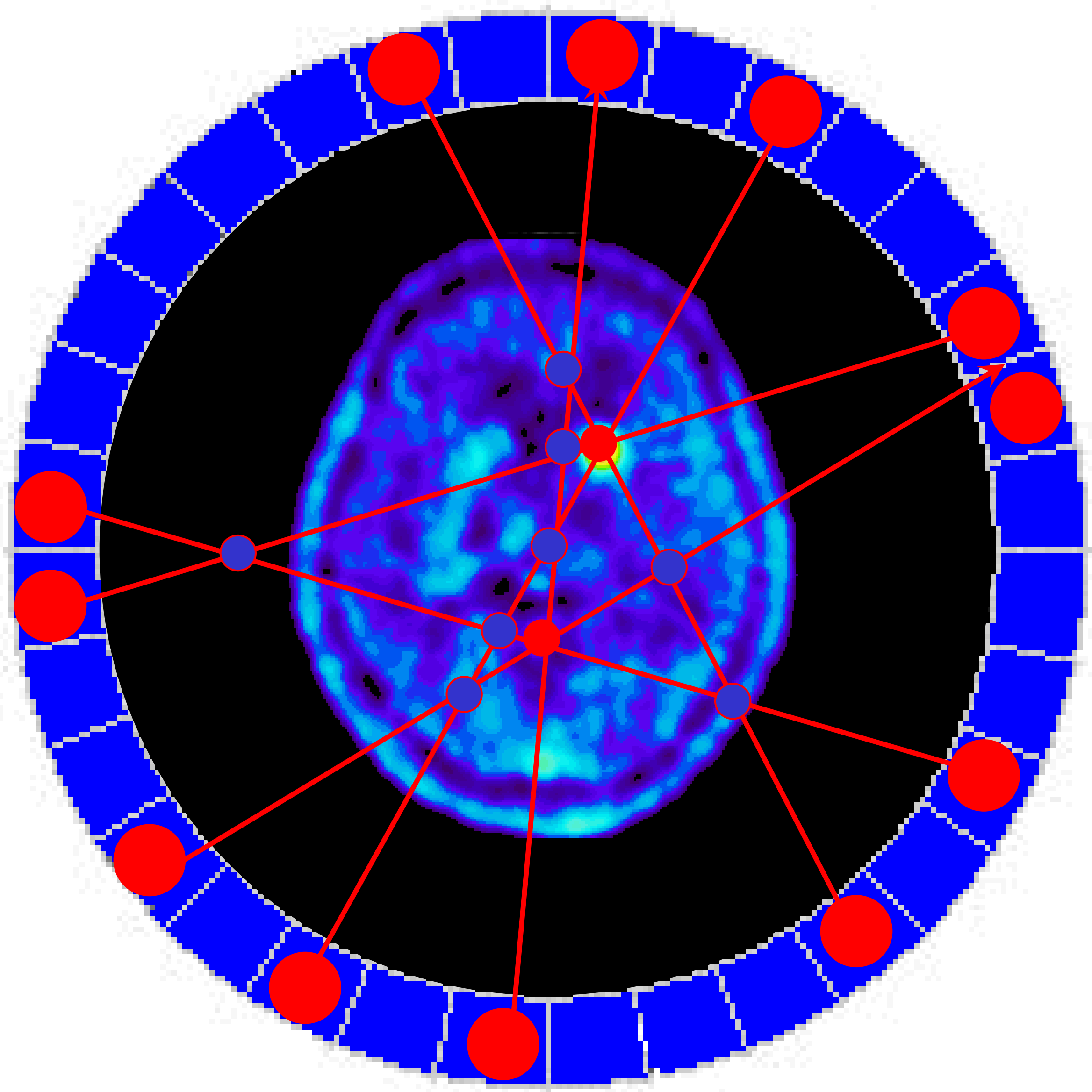






LIGHT SIGNALS FROM POLYMERS ARE MUCH „FASTER" !!!

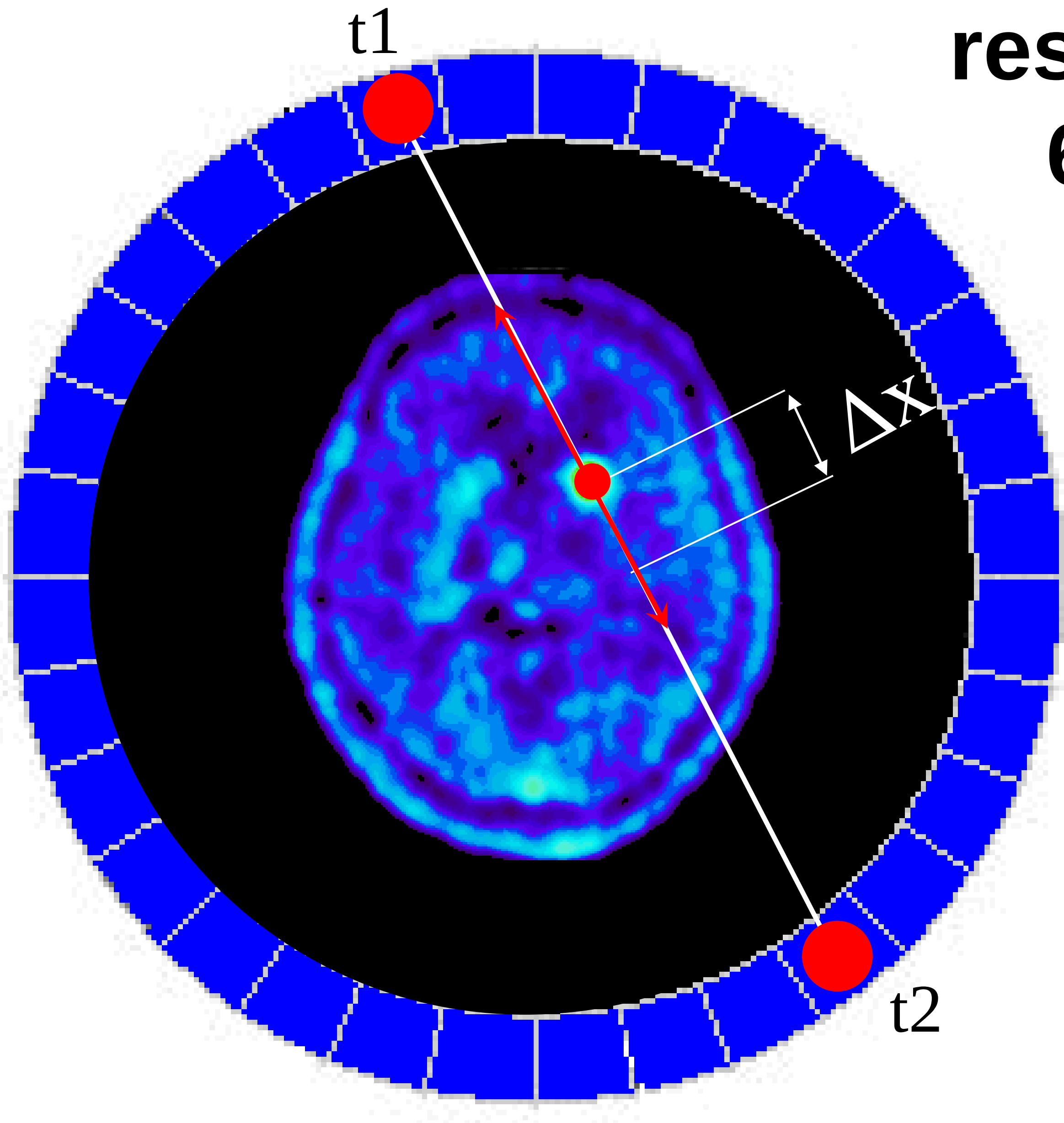
name	type	density [g/cm^3]	decay time [ns]	photons/ MeV	mean free path [cm]
BGO	crystal	7.13	300	6000	1.04
GSO	crystal	6.71	50	10000	1.49
LSO	crystal	7.40	40	29000	1.15
NE102A	polymer	1.032	2.4	10000	10.2
BC404	polymer	1.032	1.8	10000	10.2
RP422	polymer	1.032	1.6	10000	10.2

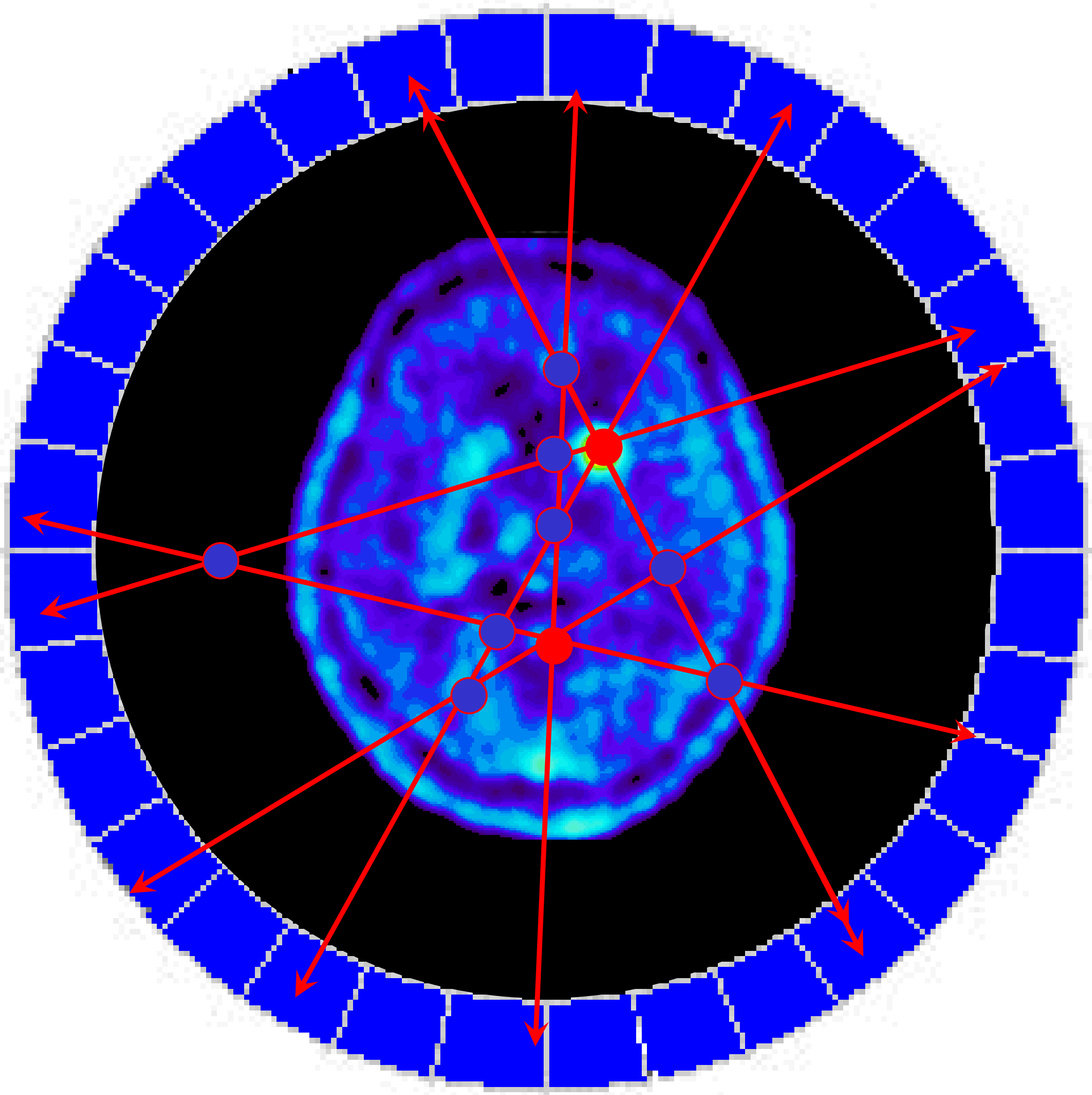


PET-TOF

$$\Delta x = (t2 - t1)\ c\ /\ 2$$

resolution 600ps



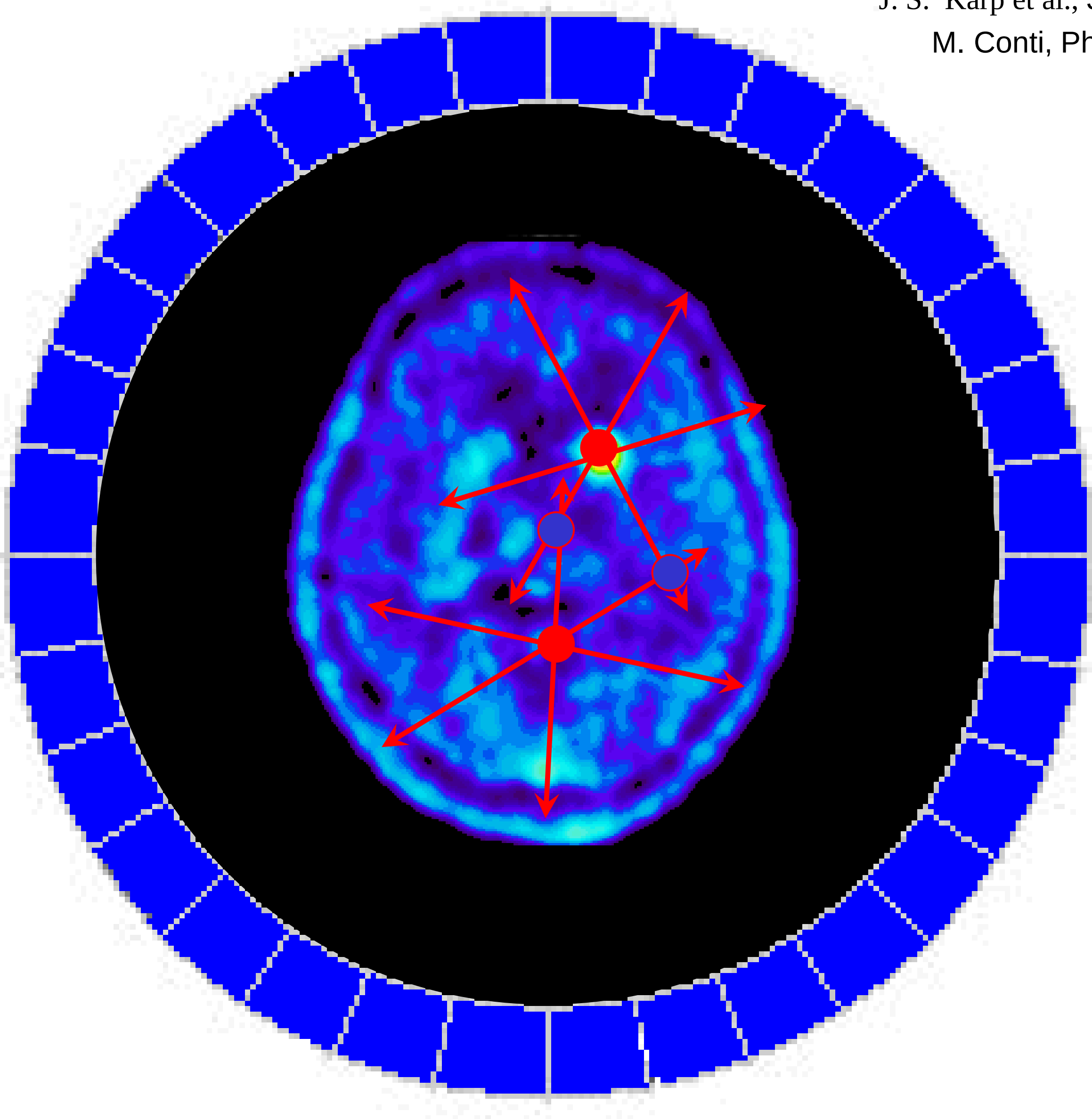


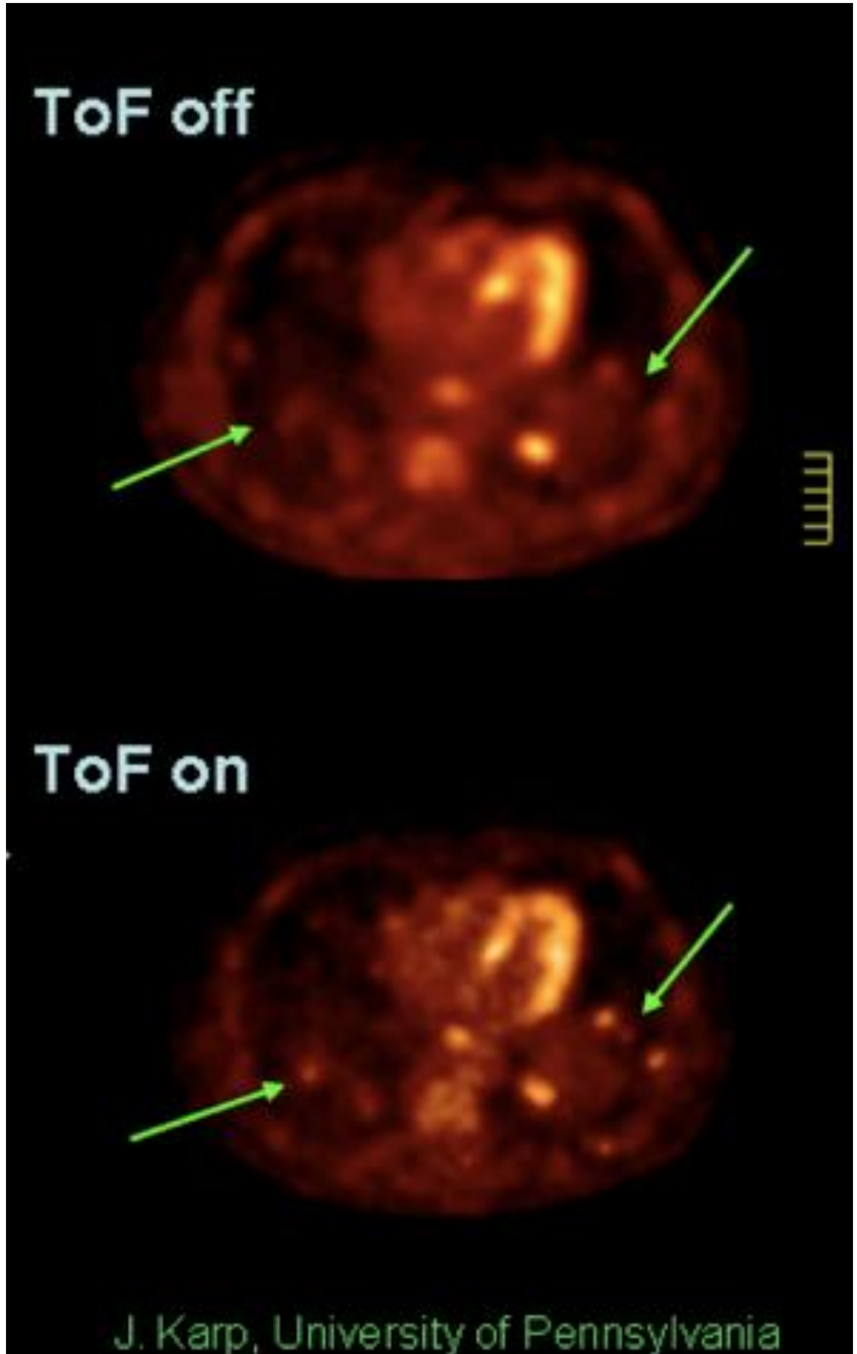
signal/background ~ D / Δt

40cm/600ps improvement by factor of 4

J. S. Karp et al., J Nucl Med 2008; 49: 462

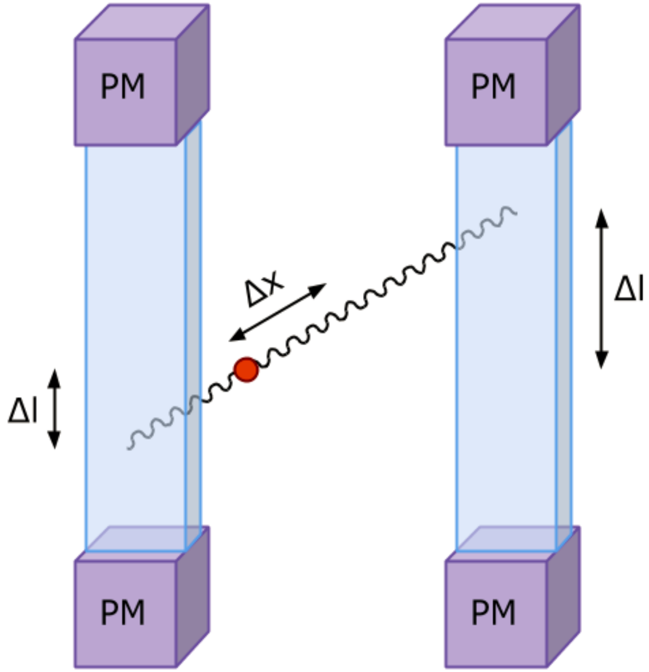
M. Conti, Physica Medica 2009; 25: 1.



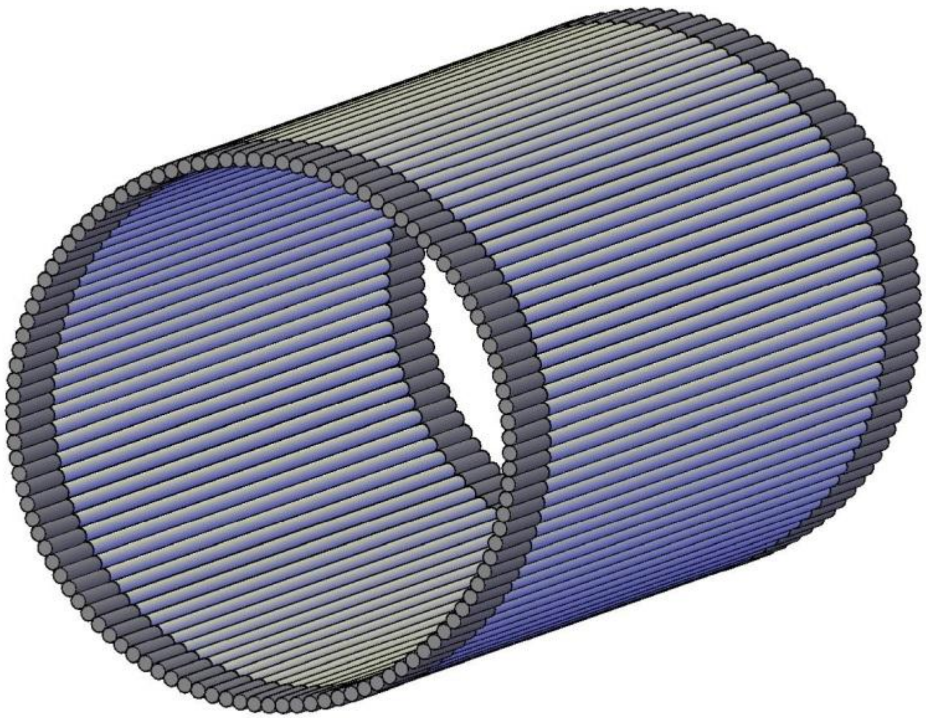

ToF off
ToF on
J. Karp, University of Pennsylvania

J-PET (**J**agiellonian **PET**)

$\Delta l = (t_2 - t_1)\, v / 2$



$\Delta x = (t\_l - t\_r)\, c / 2$



$FWHM(\Delta l) \approx FWHM(\Delta t) * c/4$

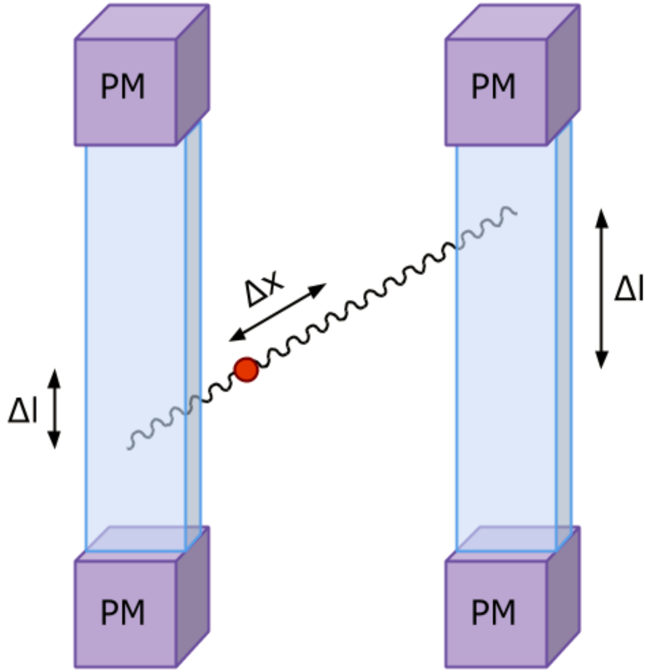
$FWHM(\Delta x) \approx FWHM(\Delta t) * c / 2\sqrt{2}$

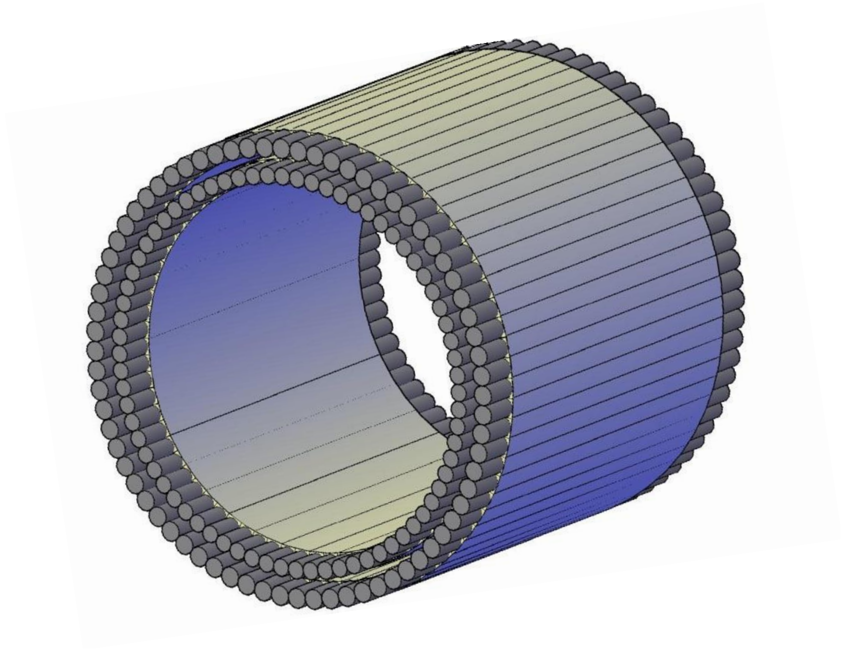
Na przykład:

$FWHM(\Delta t) = 100ps \rightarrow FWHM(\Delta l) = 0.7cm \rightarrow FWHM(\Delta x) = 1$ cm

J-PET (**J**agiellonian **PET**)

$\Delta l = (t_2 - t_1)\, v / 2$

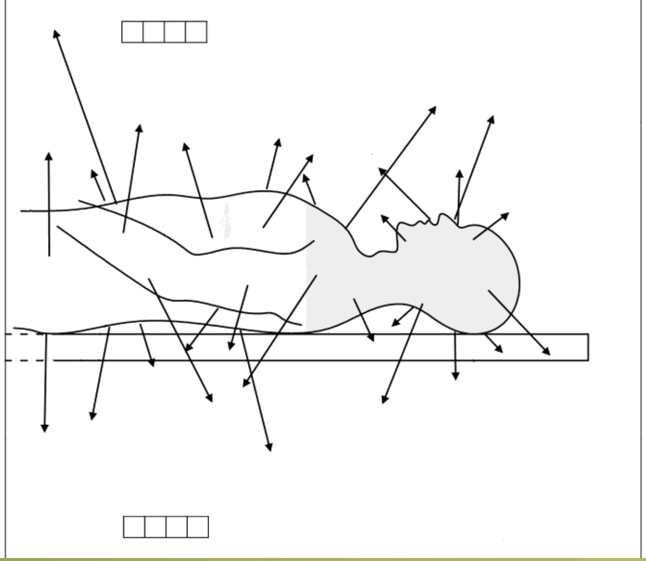


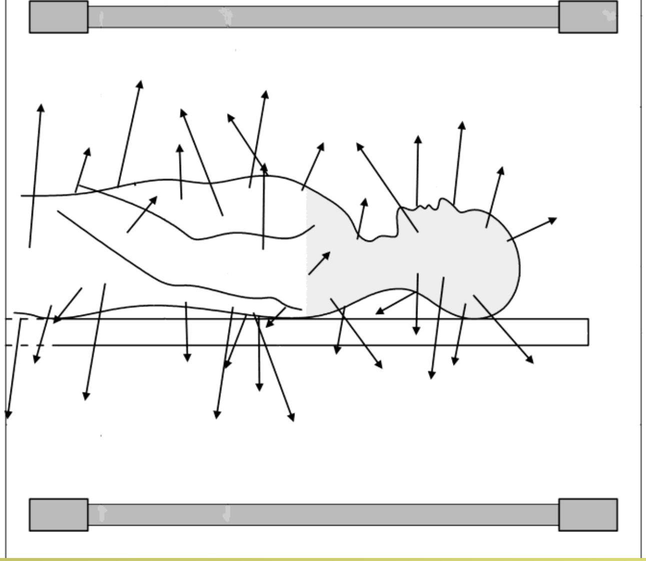


$\Delta x = (t\_l - t\_r)\, c / 2$

FWHM(Δl) ≈ FWHM(Δt) * c/4
FWHM(Δx) ≈ FWHM(Δt) * c / 2√2

Thus for example:
FWHM(Δt) = 100ps → FWHM(Δl) = 0.7cm → FWHM(Δx) = 1 cm





Koszty J-PET nie wzrastają wraz ze zwiększaniem „pola widzenia” tomografu

epsilon^2 = 20 to 40 mniejsza wydajność

ALE

2D --> 3D -------------------- > ~5

600ps --> 100ps – 200ps --> 6 -- 3

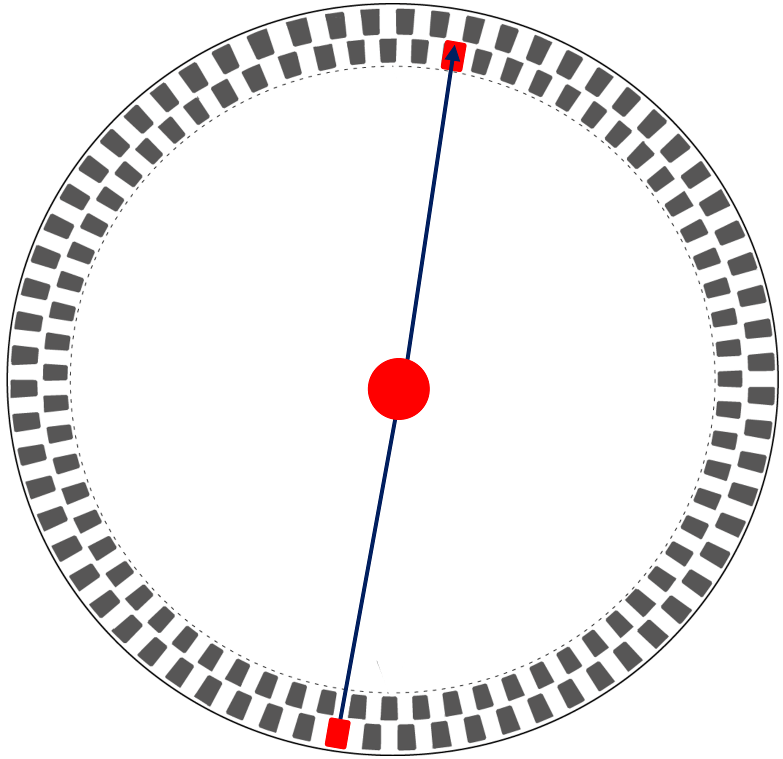
1m zamiast 20cm ------------> 9

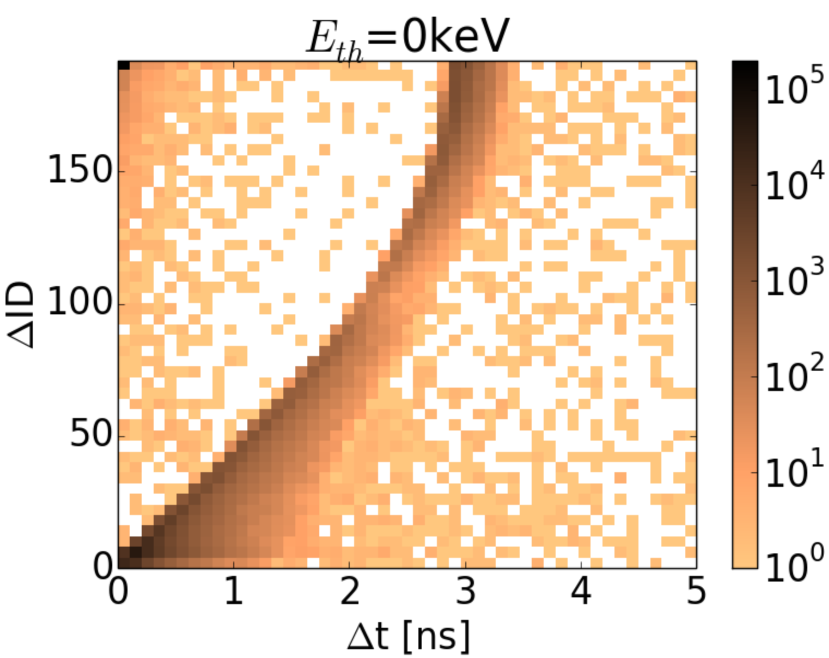
N warstw ----------------------> N^2

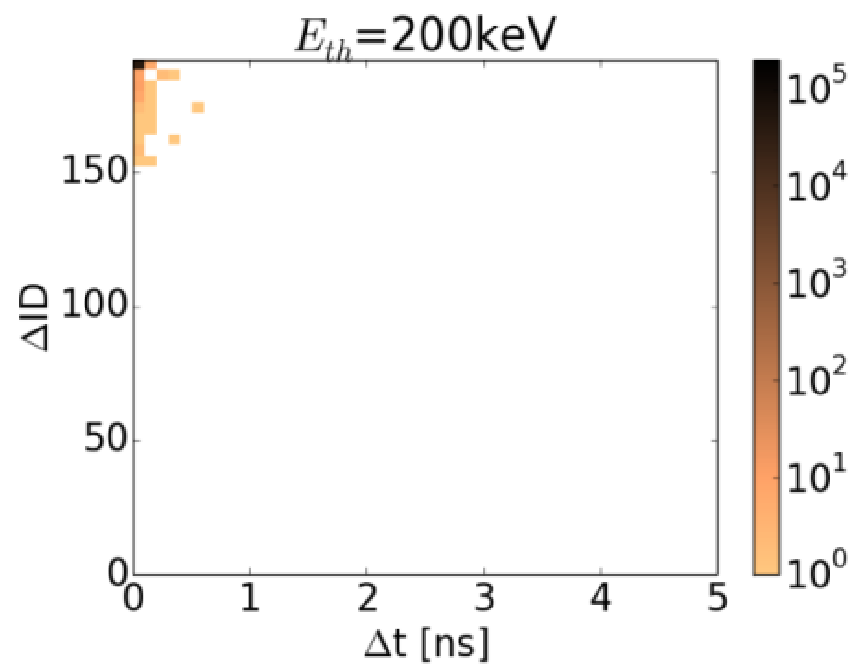
Dla N=1 --- -> czynnik ~ 200

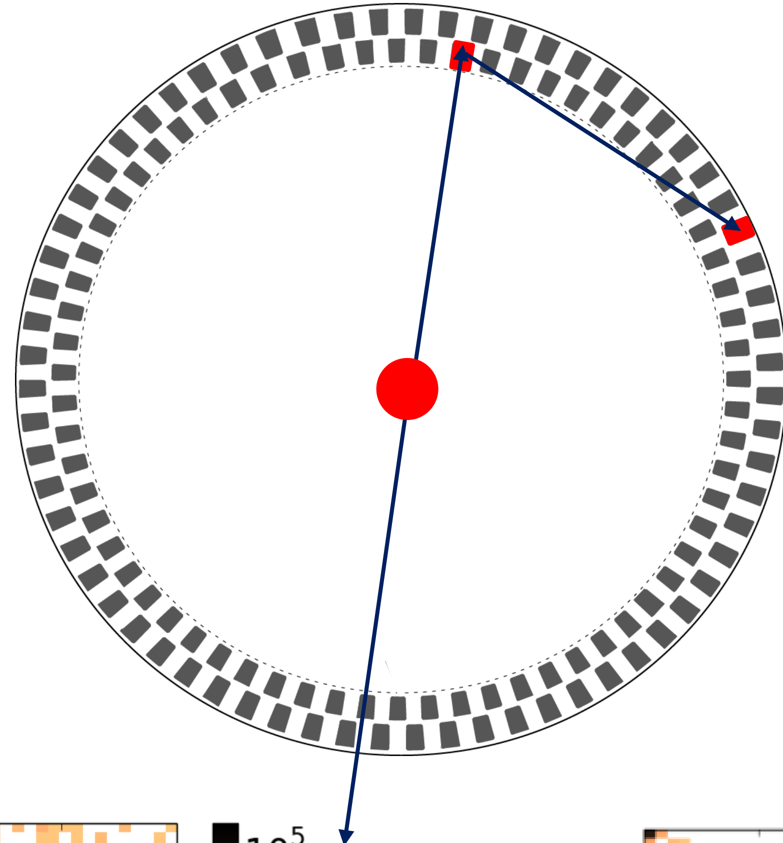
Mniejsza dawka o czynnik 7 (200 lepiej / 30 gorzej)

P. Kowalski et al.,
Acta Phys. Pol. A127 (2015)
w druku.

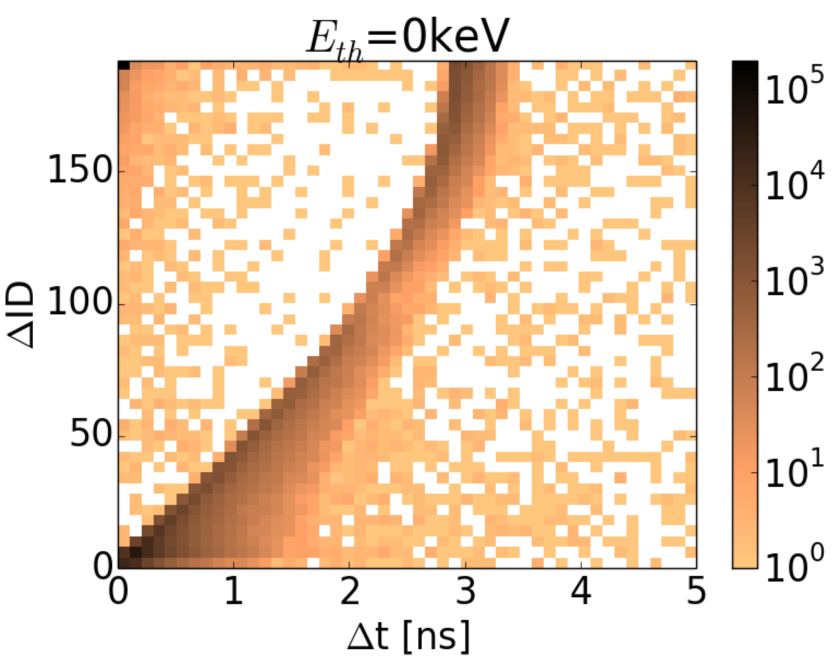


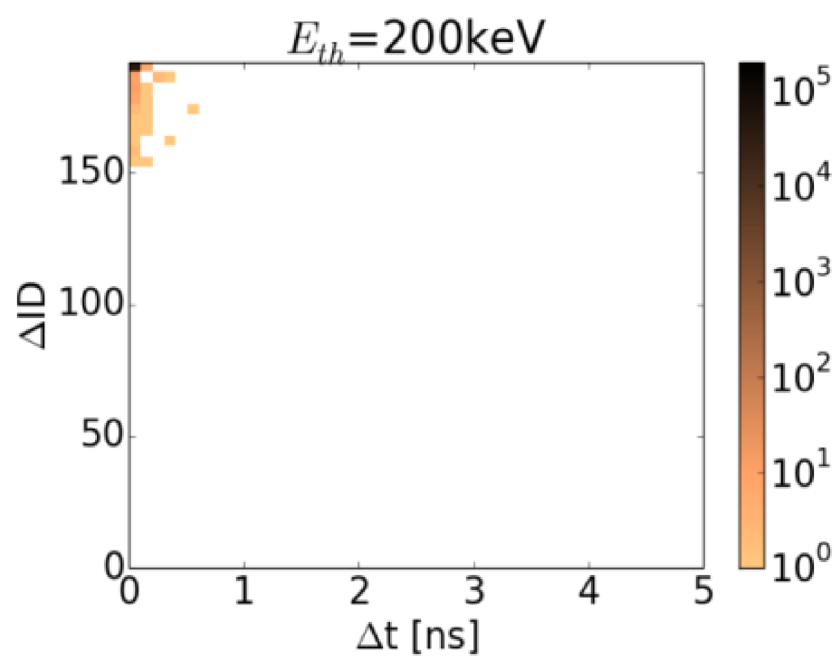


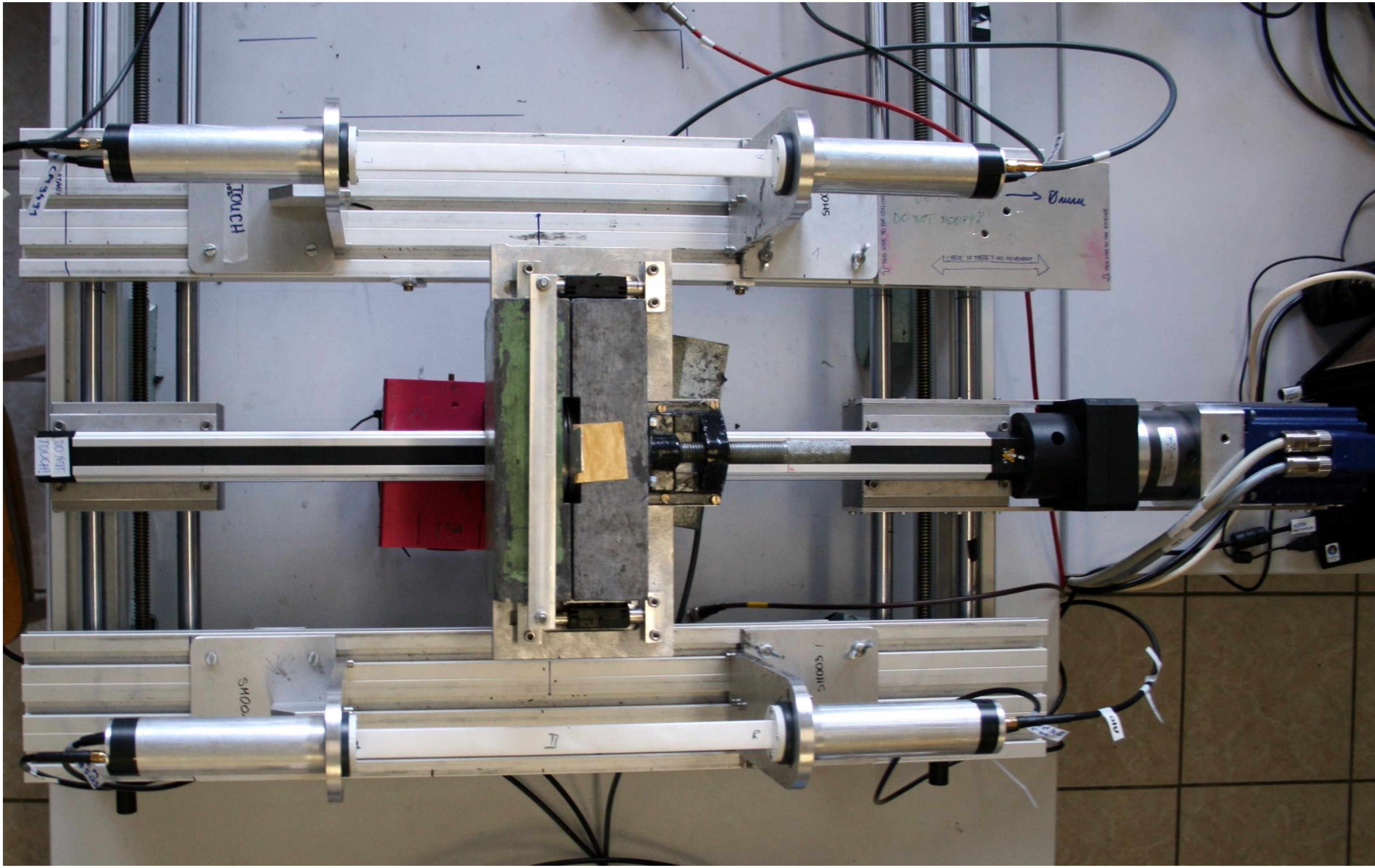


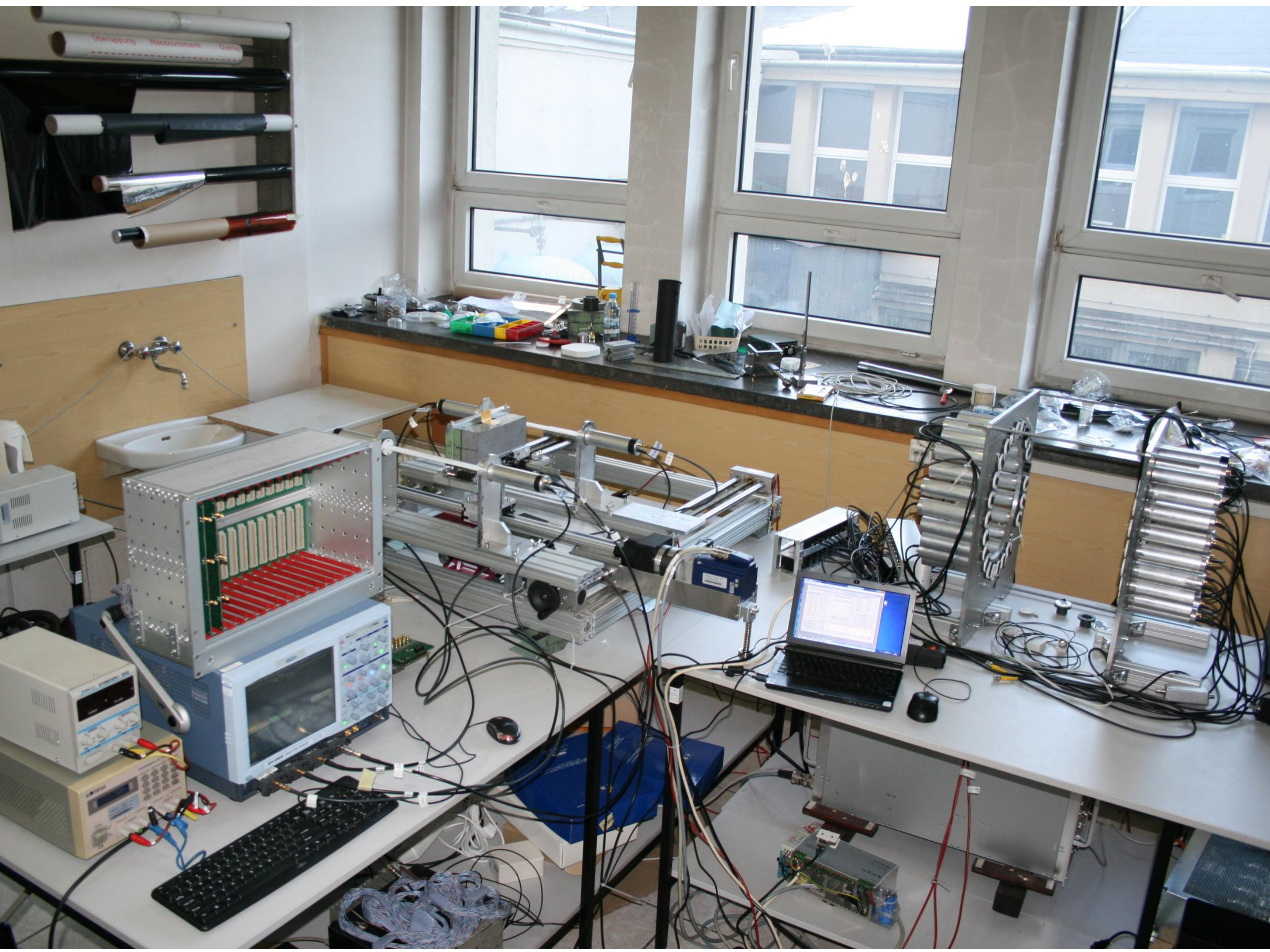


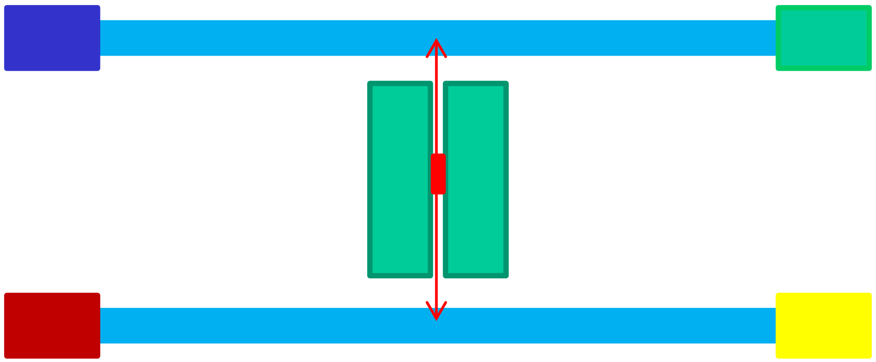
P. Kowalski et al.,
Acta Phys. Pol. A127 (2015)
w druku



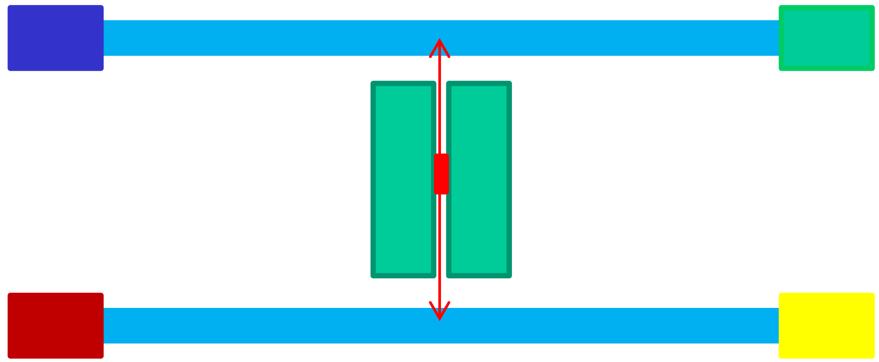



DO NOT TOUCH

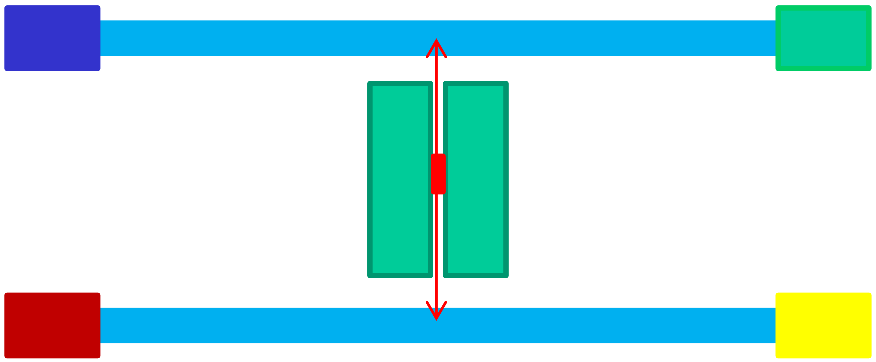


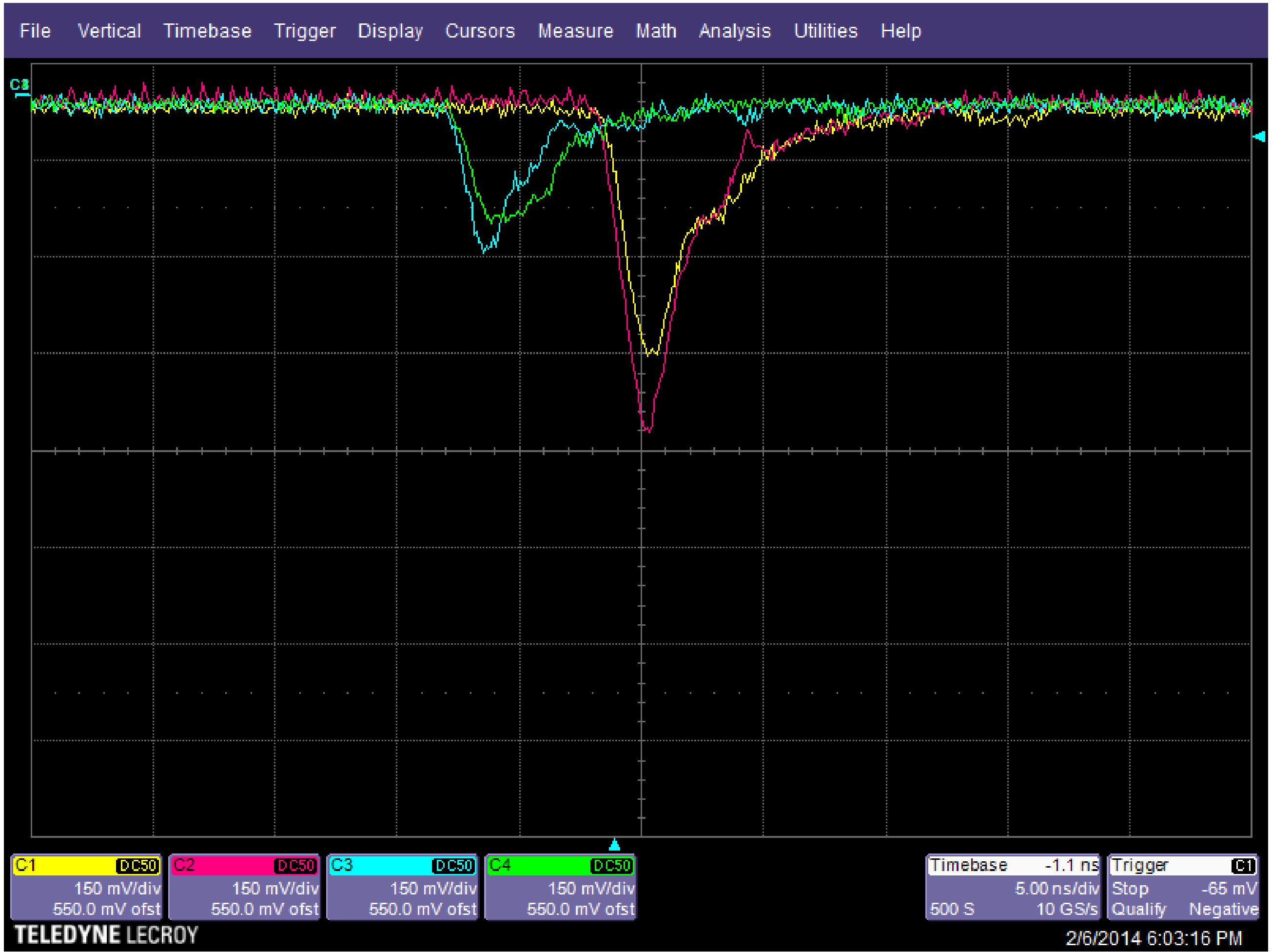


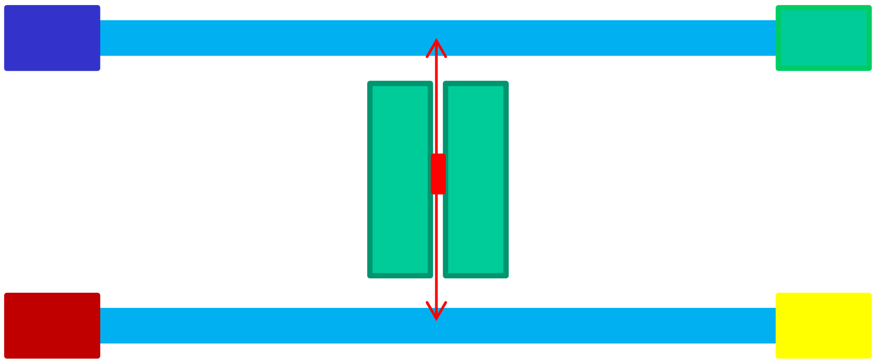

File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
C1 DC50 150 mV/div 550.0 mV ofst
C2 DC50 150 mV/div 550.0 mV ofst
C3 DC50 150 mV/div 550.0 mV ofst
C4 DC50 150 mV/div 550.0 mV ofst
Timebase -1.1 ns 5.00 ns/div 500 S 10 GS/s
Trigger C1 Stop -65 mV Qualify Negative
TELEDYNE LECROY
2/6/2014 5:55:32 PM



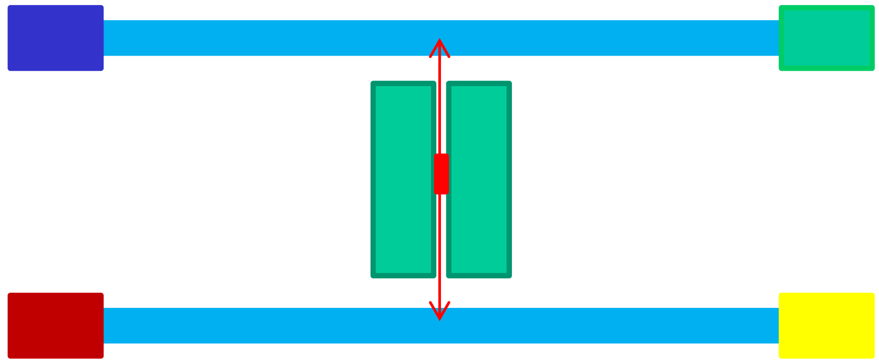

File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
C1 DC50 150 mV/div 550.0 mV ofst
C2 DC50 150 mV/div 550.0 mV ofst
C3 DC50 150 mV/div 550.0 mV ofst
C4 DC50 150 mV/div 550.0 mV ofst
Timebase -1.1 ns 5.00 ns/div 500 S 10 GS/s
Trigger C1 Stop -65 mV Qualify Negative
TELEDYNE LECROY
2/6/2014 5:58:14 PM

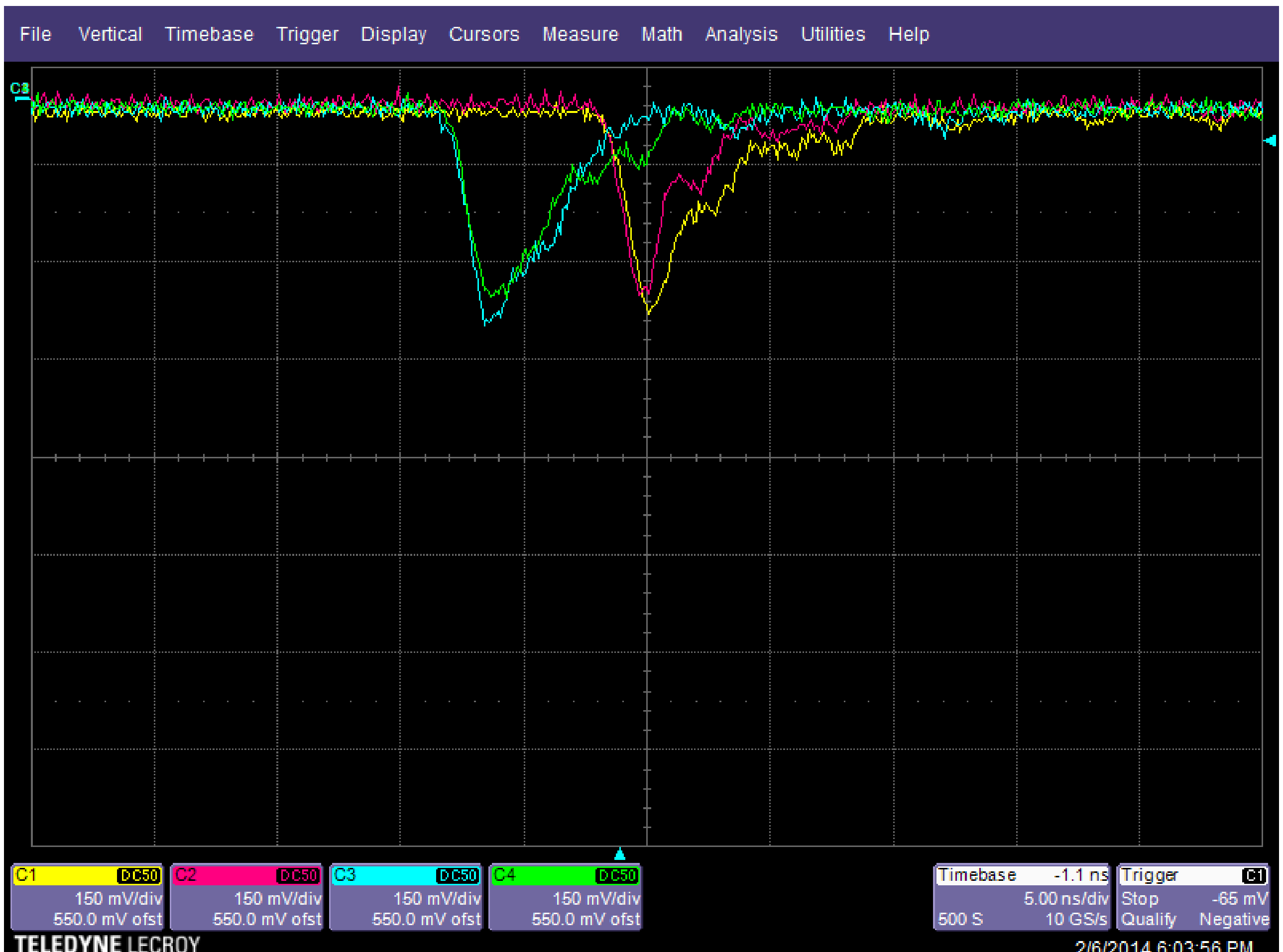


- 
File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
C1 DC50
150 mV/div
550.0 mV ofst
C2 DC50
150 mV/div
550.0 mV ofst
C3 DC50
150 mV/div
550.0 mV ofst
C4 DC50
150 mV/div
550.0 mV ofst
Timebase -1.1 ns
5.00 ns/div
500 S 10 GS/s
Trigger C1
Stop -65 mV
Qualify Negative
TELEDYNE LECROY
2/6/2014 6:03:16 PM



File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
C1 DC50
150 mV/div
550.0 mV ofst
C2 DC50
150 mV/div
550.0 mV ofst
C3 DC50
150 mV/div
550.0 mV ofst
C4 DC50
150 mV/div
550.0 mV ofst
Timebase -1.1 ns
5.00 ns/div
500 S 10 GS/s
Trigger C1
Stop -65 mV
Qualify Negative
TELEDYNE LECROY
2/6/2014 5:56:15 PM





File
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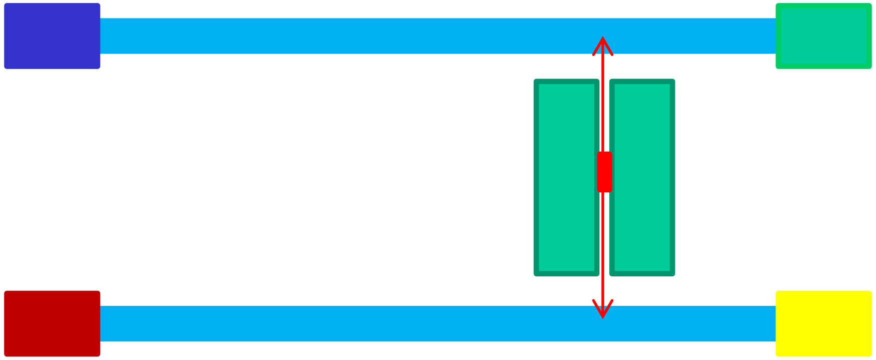
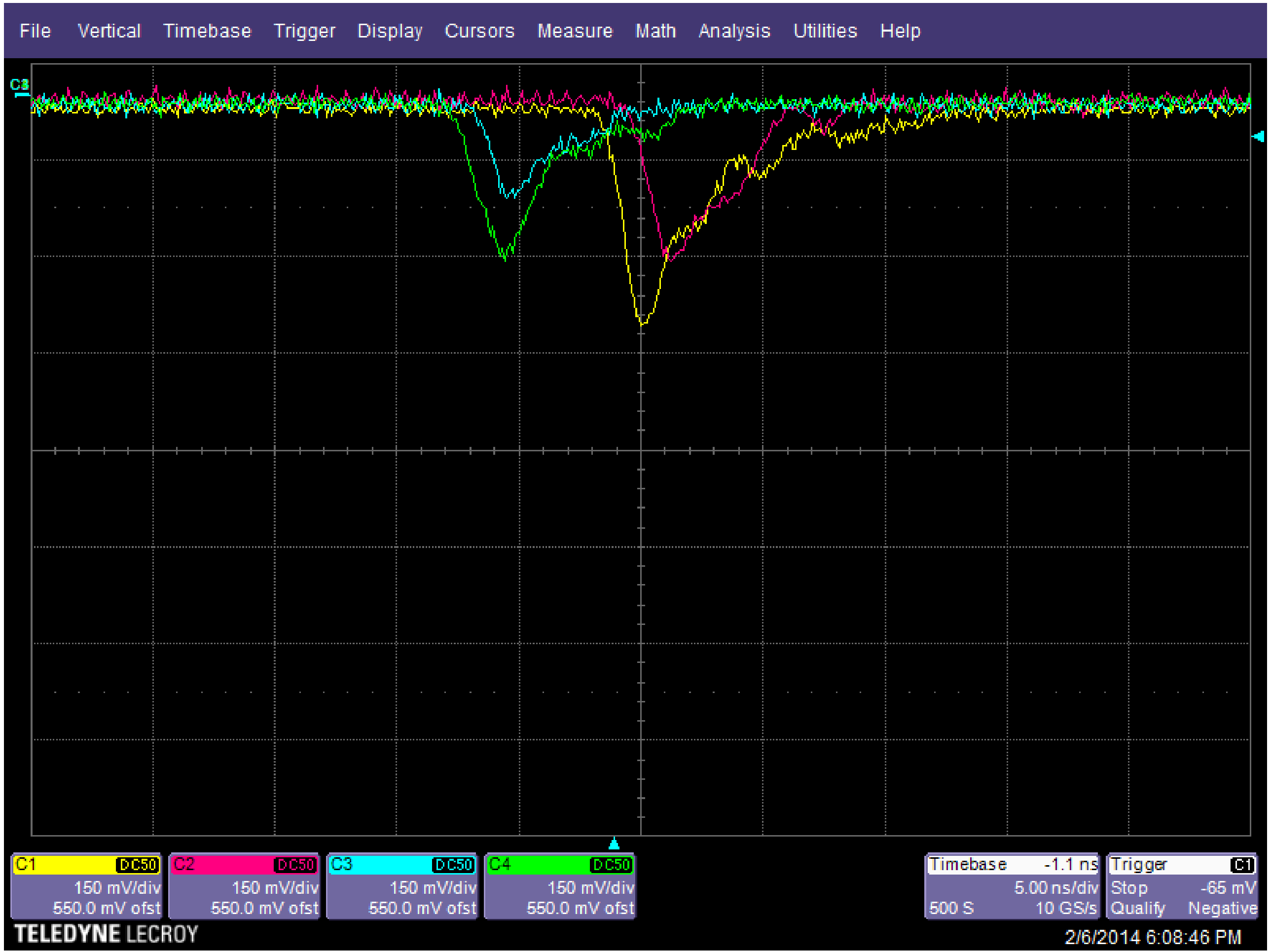
Display
Cursors
Measure
Math
Analysis
Utilities
Help
C1 DC50
150 mV/div
550.0 mV ofst
C2 DC50
150 mV/div
550.0 mV ofst
C3 DC50
150 mV/div
550.0 mV ofst
C4 DC50
150 mV/div
550.0 mV ofst
Timebase -1.1 ns
5.00 ns/div
500 S 10 GS/s
Trigger C1
Stop -65 mV
Qualify Negative
TELEDYNE LECROY
2/6/2014 6:03:56 PM




File
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C1 DC50
150 mV/div
550.0 mV ofst
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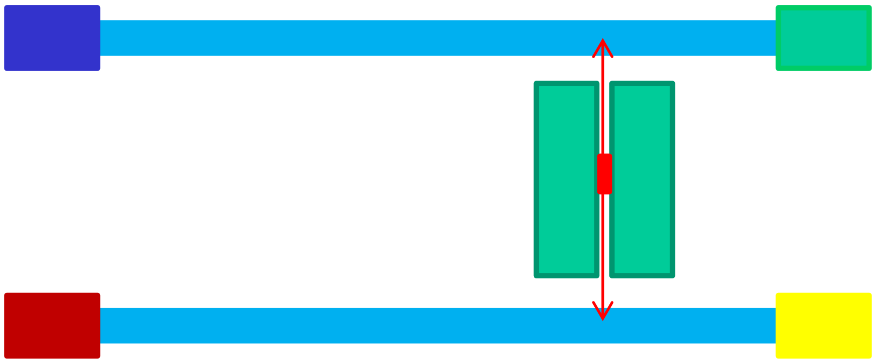
C3 DC50
150 mV/div
550.0 mV ofst
C4 DC50
150 mV/div
550.0 mV ofst
Timebase -1.1 ns
5.00 ns/div
500 S 10 GS/s
Trigger C1
Stop -65 mV
Qualify Negative
TELEDYNE LECROY
2/6/2014 6:08:46 PM



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C1 DC50
150 mV/div
550.0 mV ofst
C2 DC50
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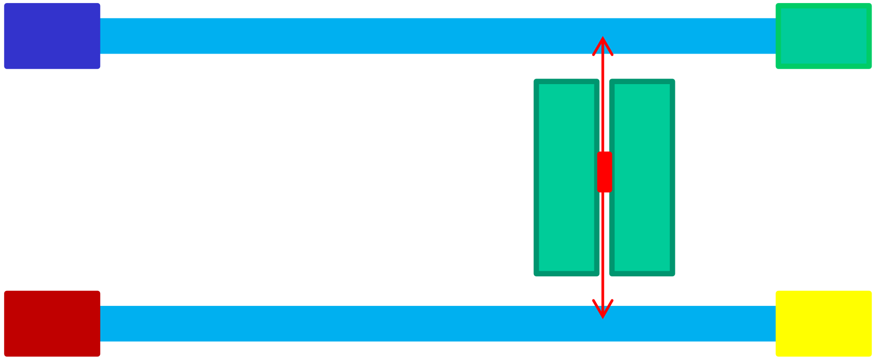
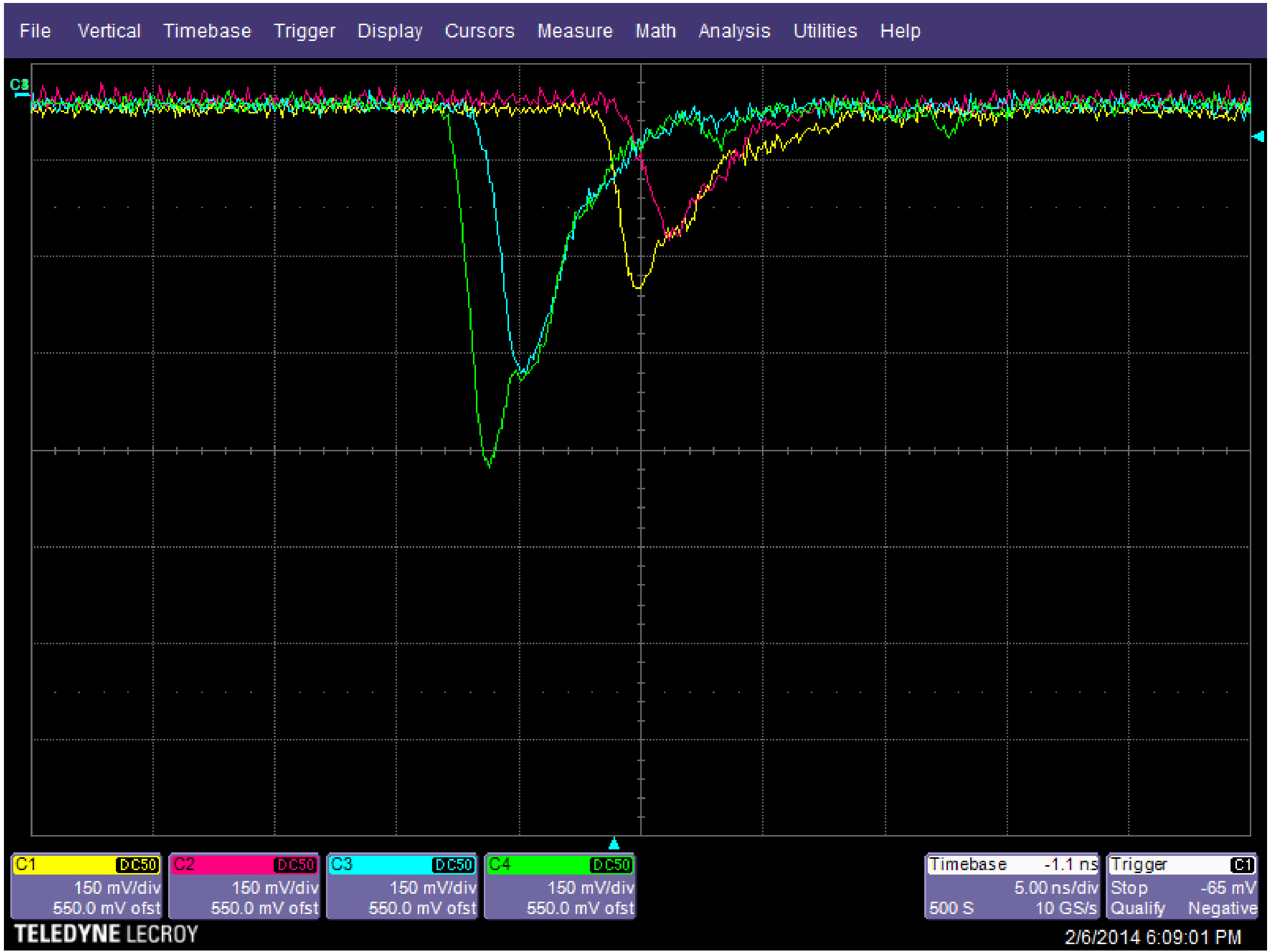
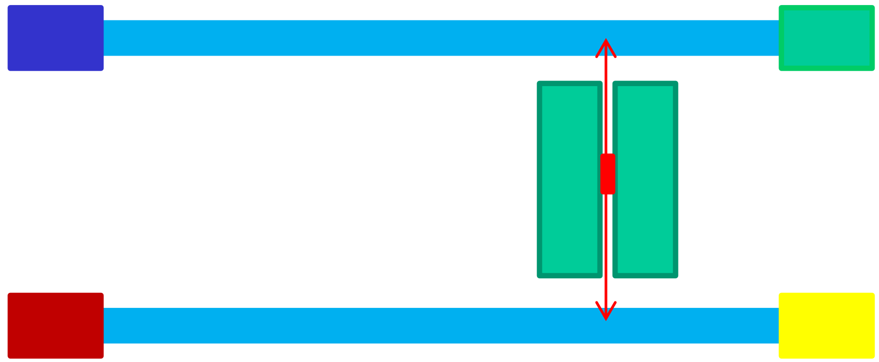
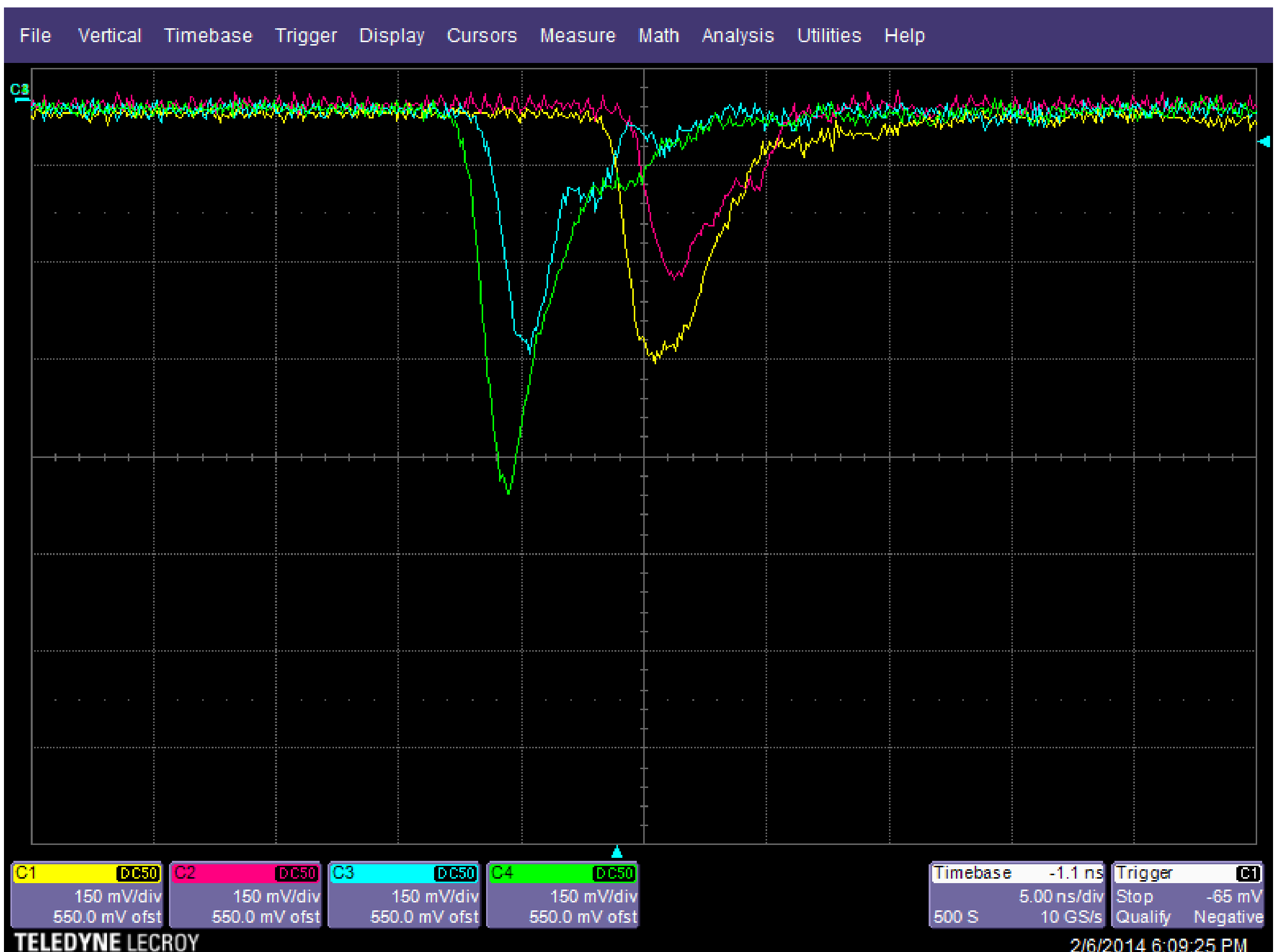
550.0 mV ofst
C3 DC50
150 mV/div
550.0 mV ofst
C4 DC50
150 mV/div
550.0 mV ofst
Timebase -1.1 ns
5.00 ns/div
500 S 10 GS/s
Trigger C1
Stop -65 mV
Qualify Negative
TELEDYNE LECROY
2/6/2014 6:07:45 PM



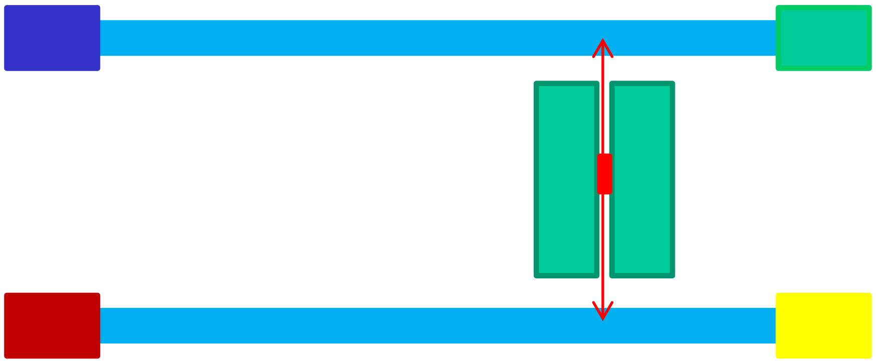


File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
C1 DC50 150 mV/div 550.0 mV ofst
C2 DC50 150 mV/div 550.0 mV ofst
C3 DC50 150 mV/div 550.0 mV ofst
C4 DC50 150 mV/div 550.0 mV ofst
Timebase -1.1 ns 5.00 ns/div 500 S 10 GS/s
Trigger C1 Stop -65 mV Qualify Negative
TELEDYNE LECROY
2/6/2014 6:09:01 PM

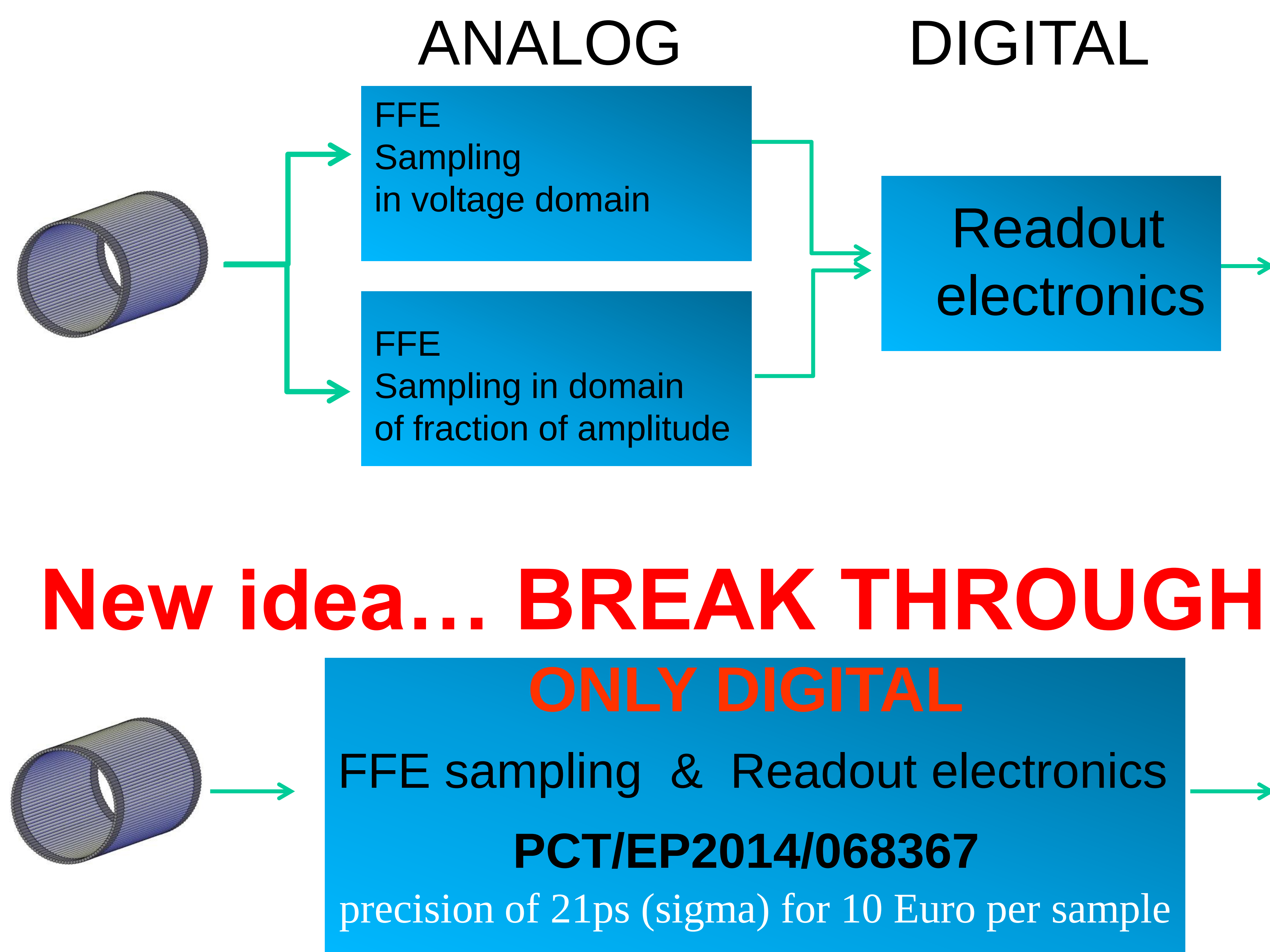


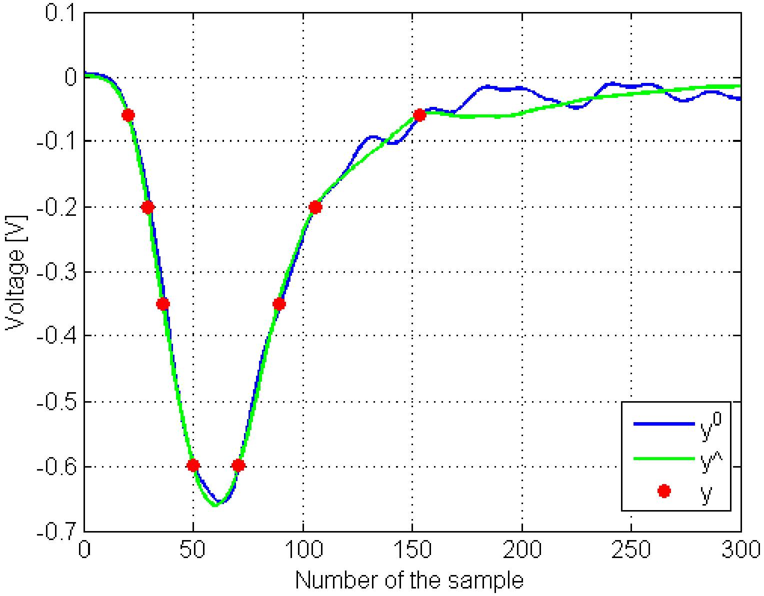


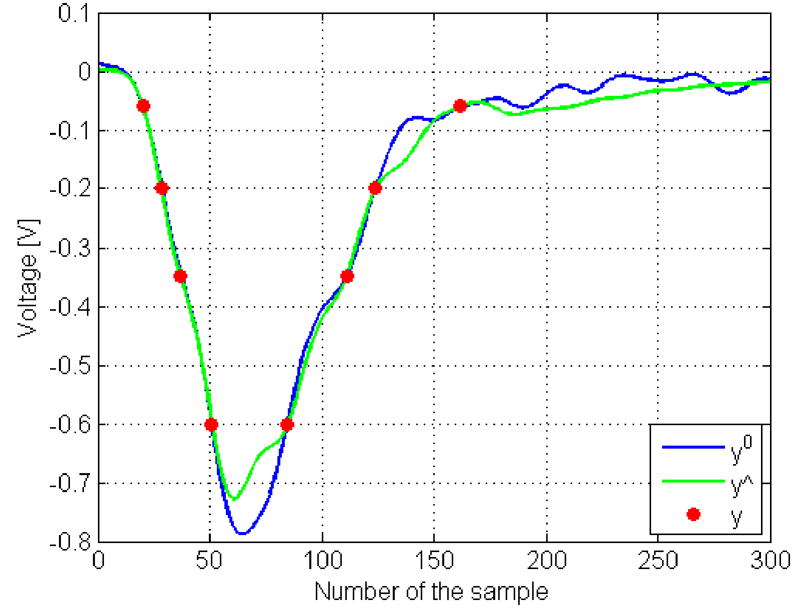
File
Vertical
Timebase
Trigger
Display
Cursors
Measure
Math
Analysis
Utilities
Help
C3
C1 DC50
150 mV/div
550.0 mV ofst
C2 DC50
150 mV/div
550.0 mV ofst
C3 DC50
150 mV/div
550.0 mV ofst
C4 DC50
150 mV/div
550.0 mV ofst
Timebase -1.1 ns
5.00 ns/div
500 S 10 GS/s
Trigger C1
Stop -65 mV
Qualify Negative
TELEDYNE LECROY
2/6/2014 6:09:25 PM

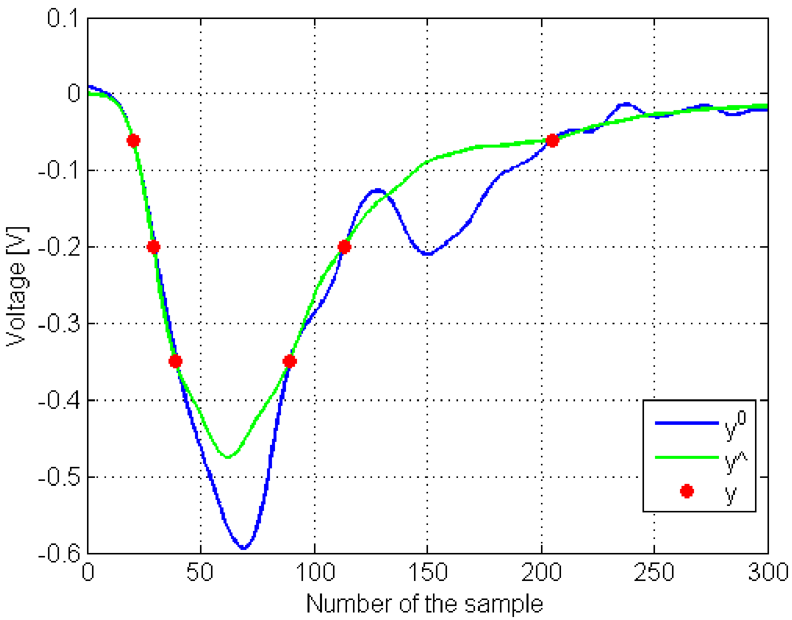



File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
C1 DC50
150 mV/div
550.0 mV ofst
C2 DC50
150 mV/div
550.0 mV ofst
C3 DC50
150 mV/div
550.0 mV ofst
C4 DC50
150 mV/div
550.0 mV ofst
Timebase -1.1 ns
5.00 ns/div
500 S 10 GS/s
Trigger C1
Stop -65 mV
Qualify Negative
TELEDYNE LECROY
2/6/2014 6:08:02 PM

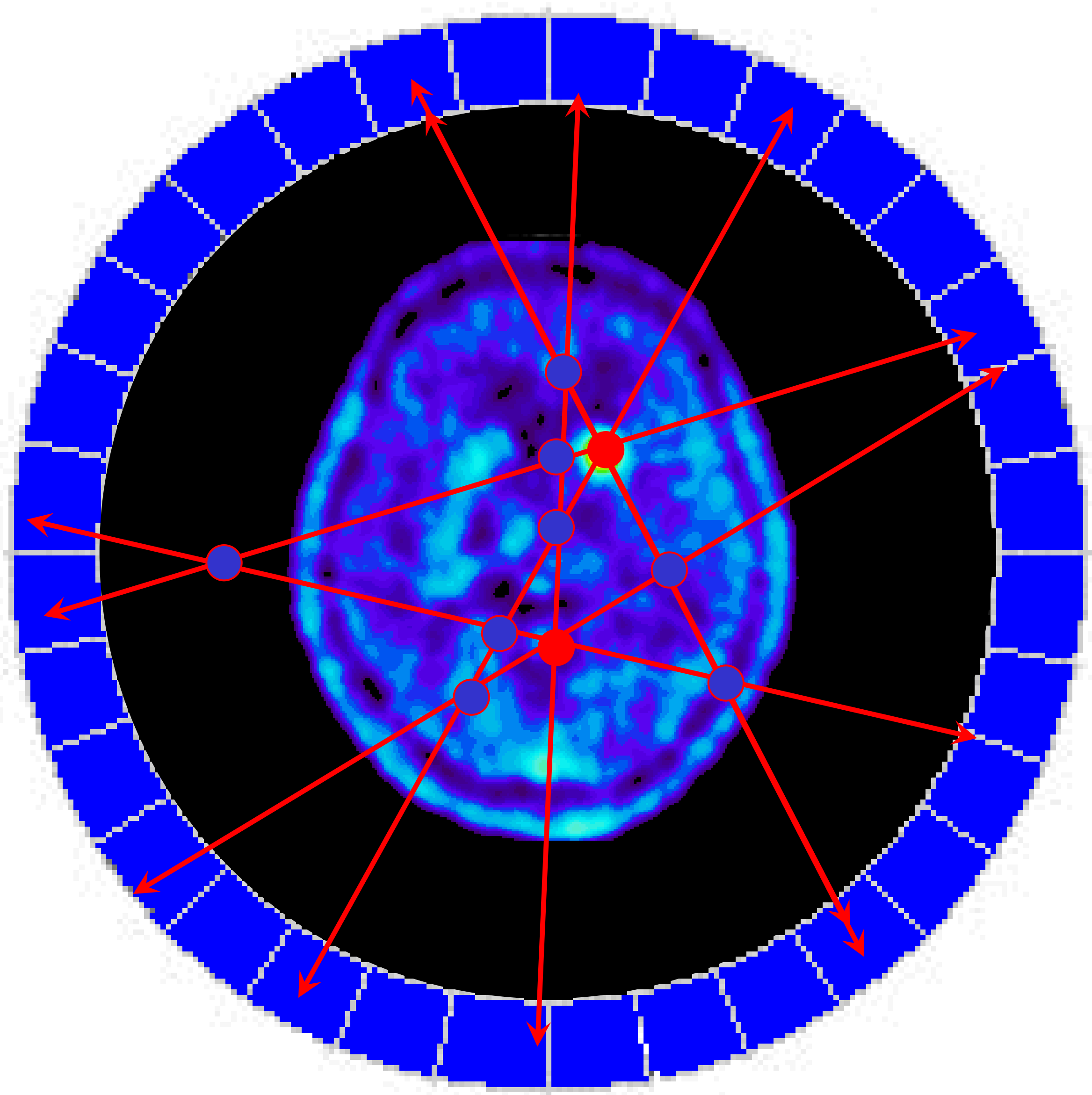

ANALOG
DIGITAL
FFE
Sampling
in voltage domain
FFE
Sampling in domain
of fraction of amplitude
Readout
electronics
New idea… BREAK THROUGH
ONLY DIGITAL
FFE sampling & Readout electronics
PCT/EP2014/068367
precision of 21ps (sigma) for 10 Euro per sample







Library of signals
Principal Component Analysis
Compressive Sensing
L. Raczyński et al.,
NIM A786 (2015) 105



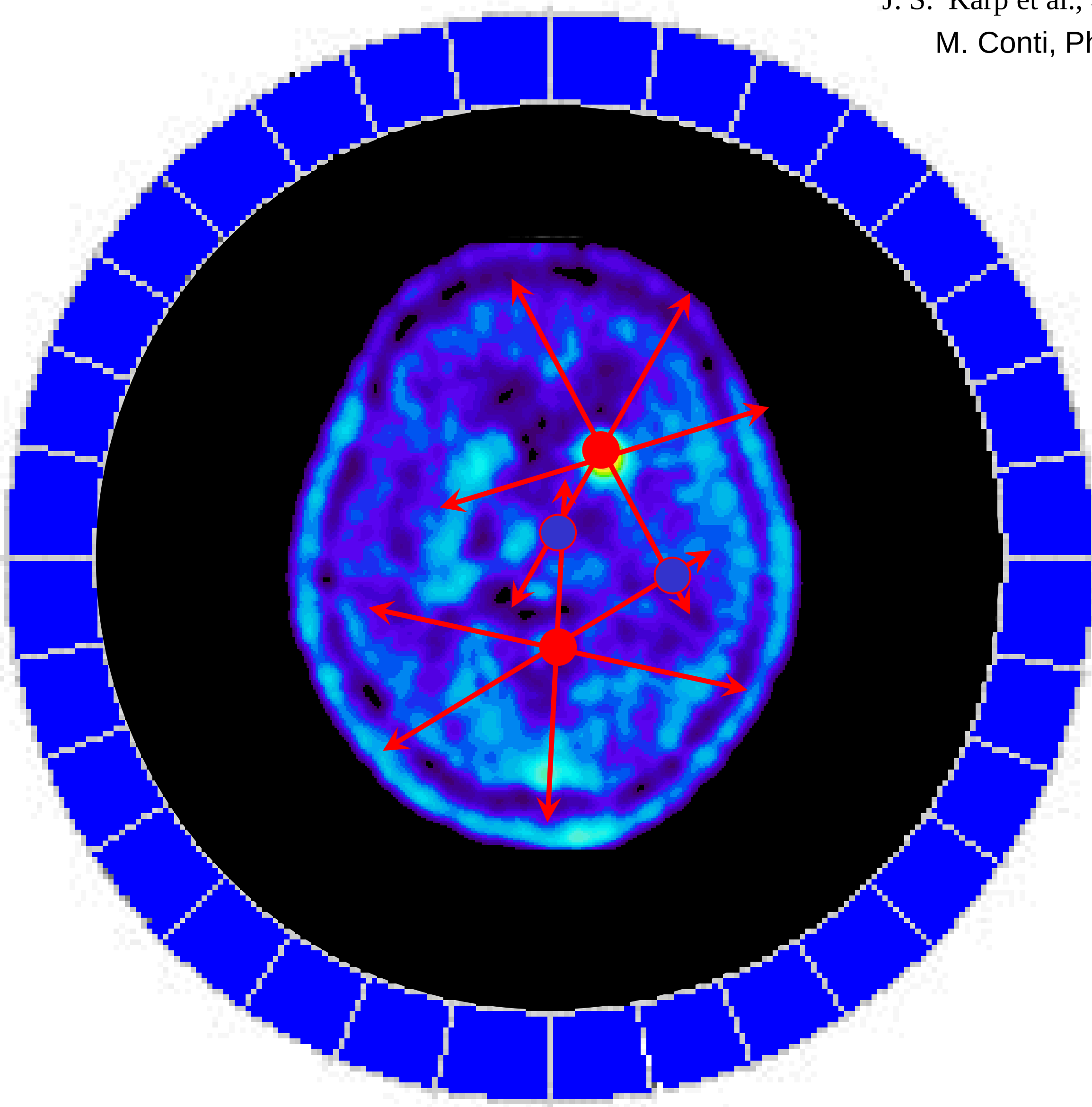
signal/background

~ D / Δt

40cm/600ps improvement by factor of 4

J. S. Karp et al., J Nucl Med 2008; 49: 462

M. Conti, Physica Medica 2009; 25: 1.



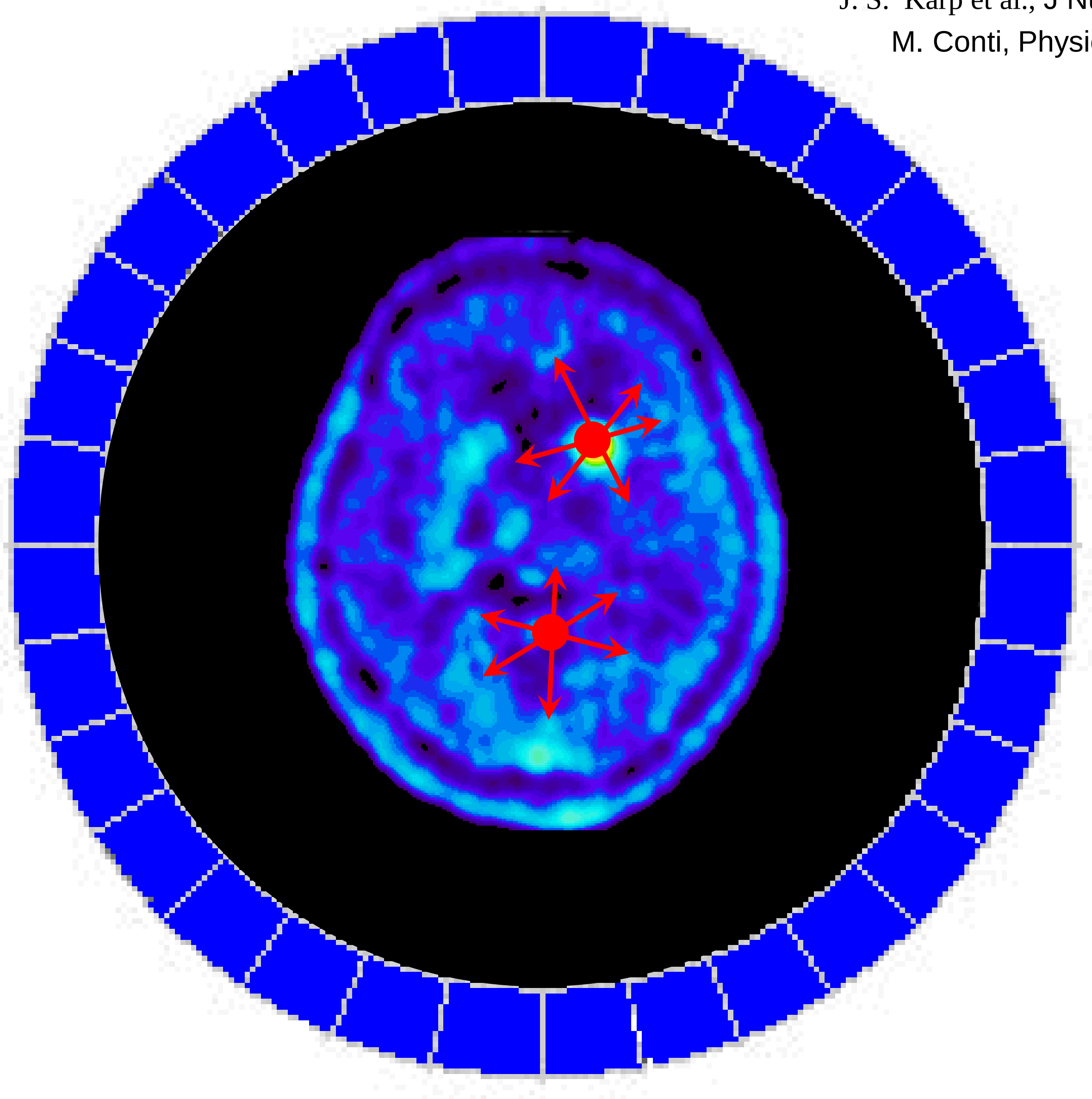
signal/background

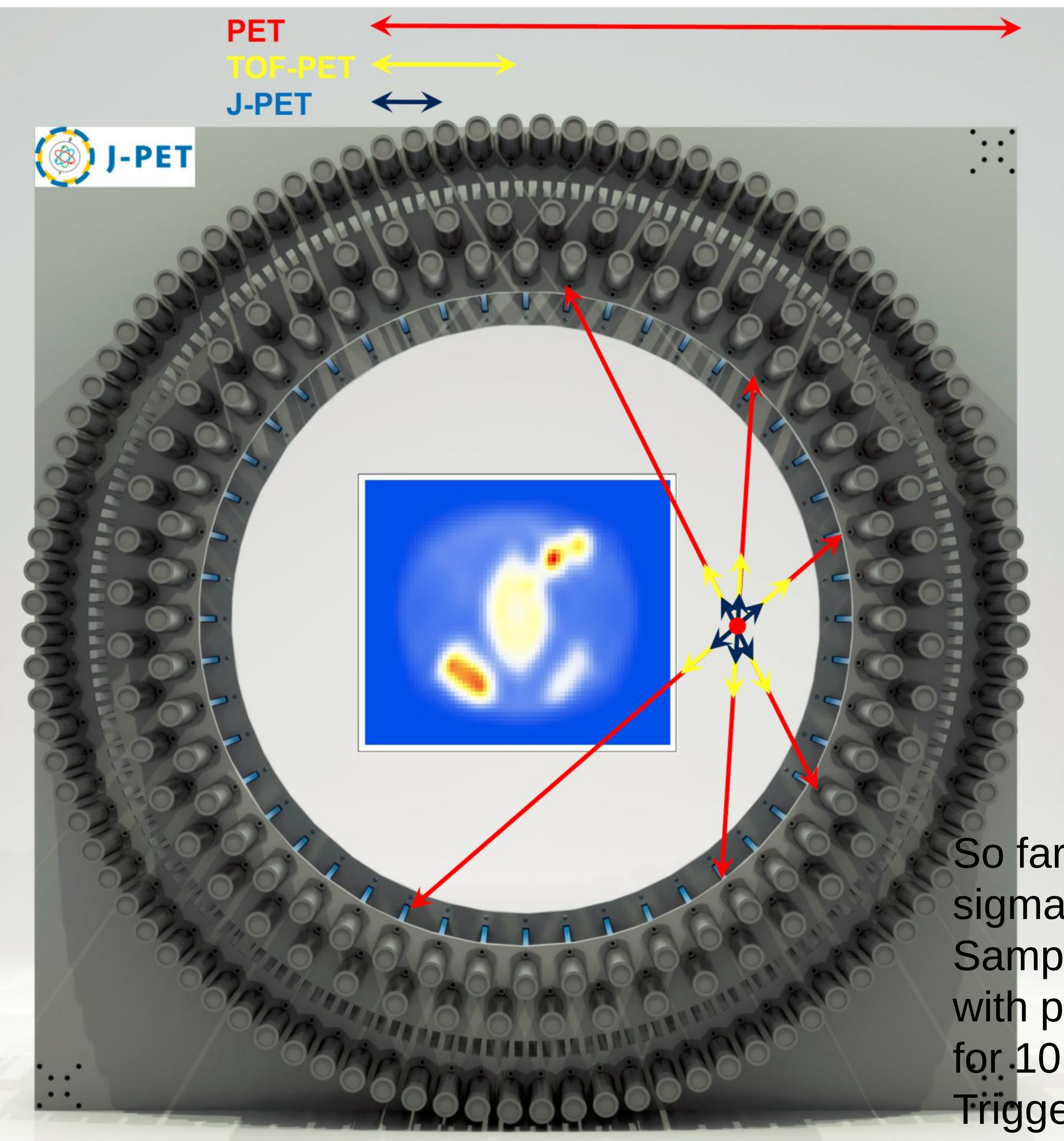
$\sim D / \Delta t$

40cm/200ps improvement by factor of 12

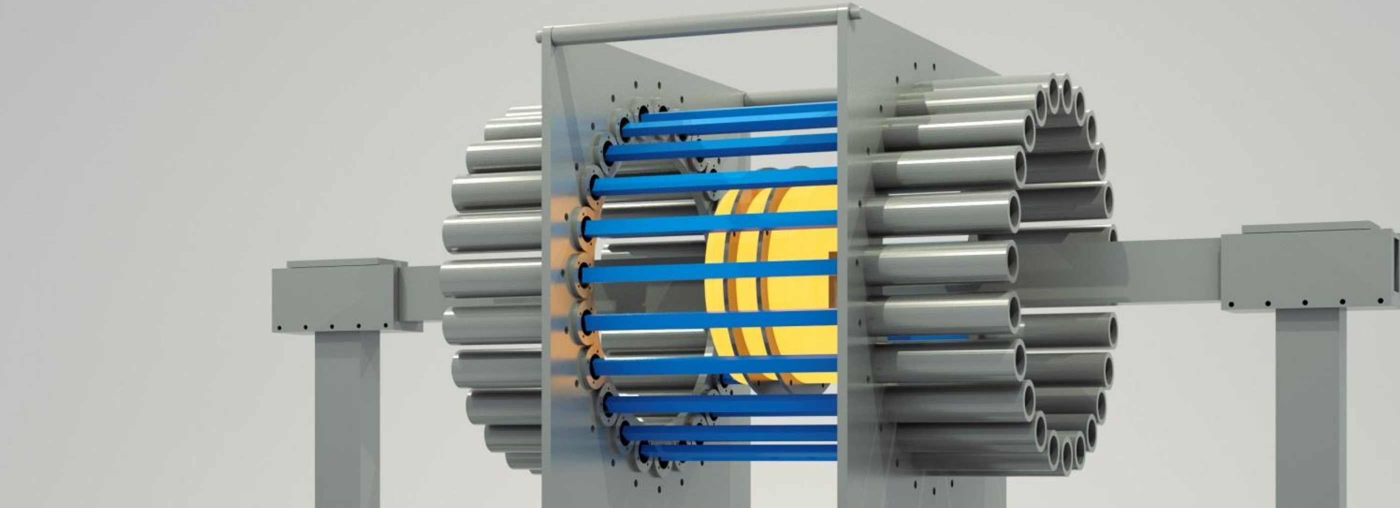
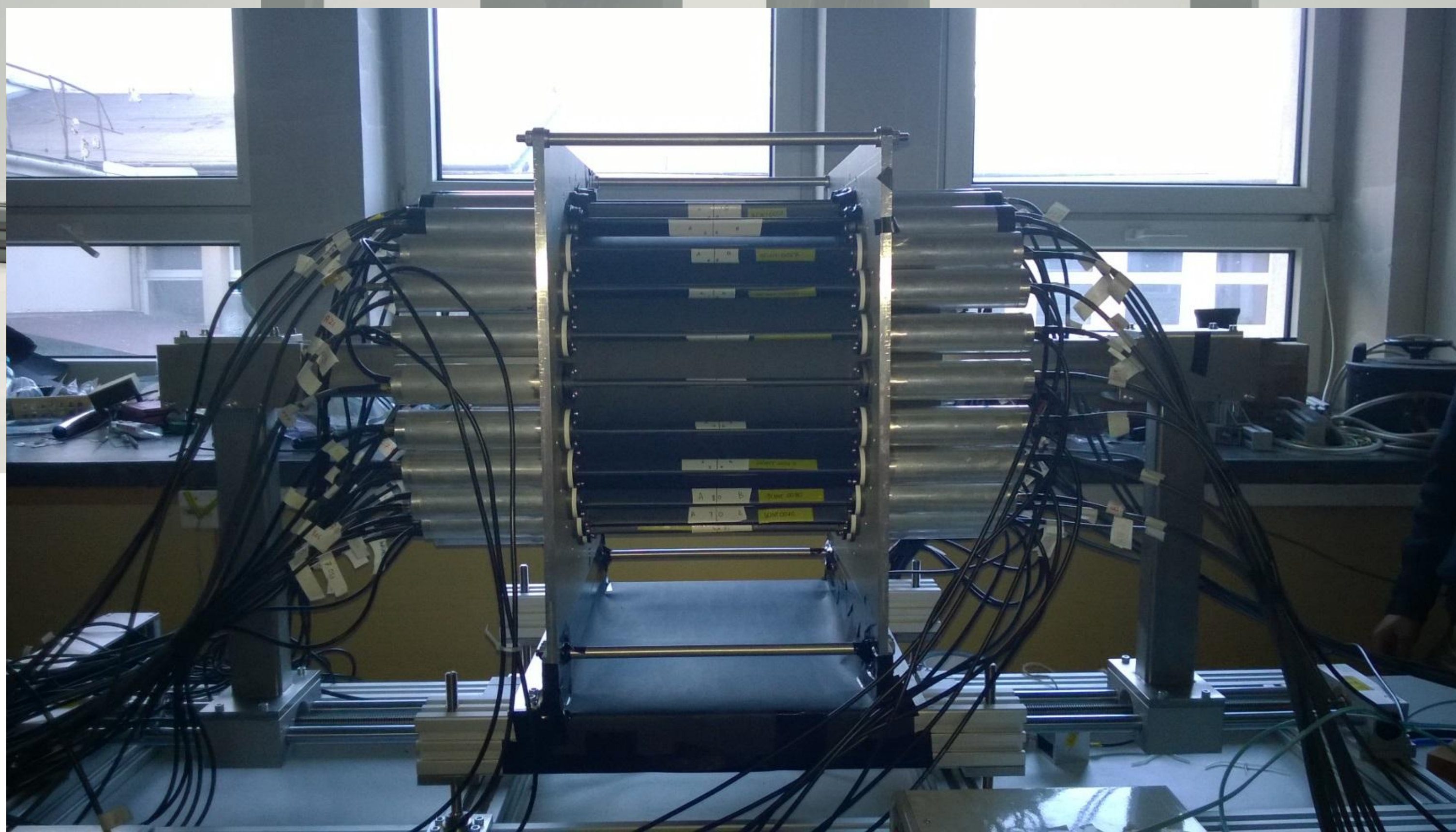
J. S. Karp et al., J Nucl Med 2008; 49: 462

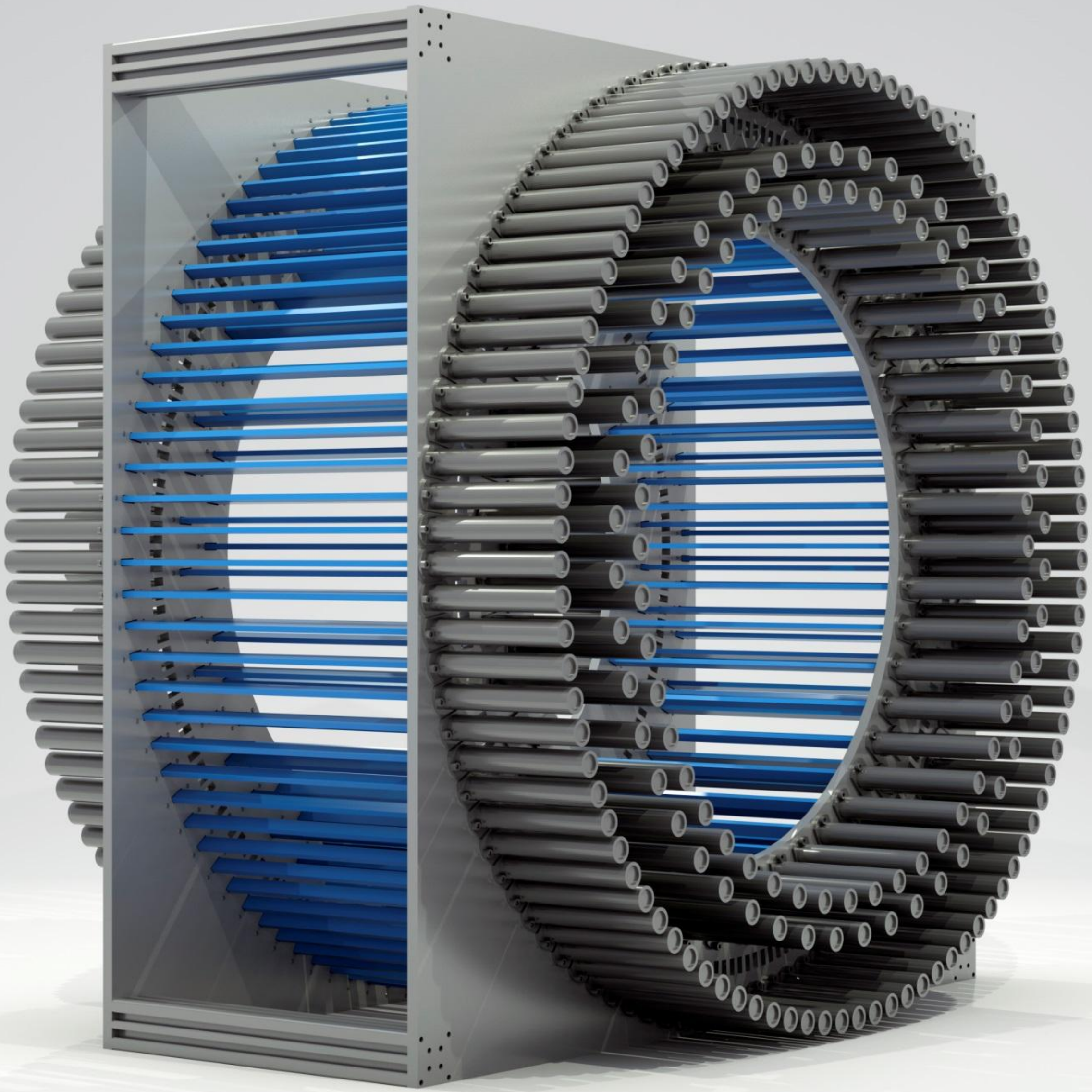
M. Conti, Physica Medica 2009; 25: 1.





So far:
sigma(TOF) = 100ps ;
Sampling in voltage domain
with precision of 21ps (sigma)
for 10 Euro per sample;
Triggerless DAQ;

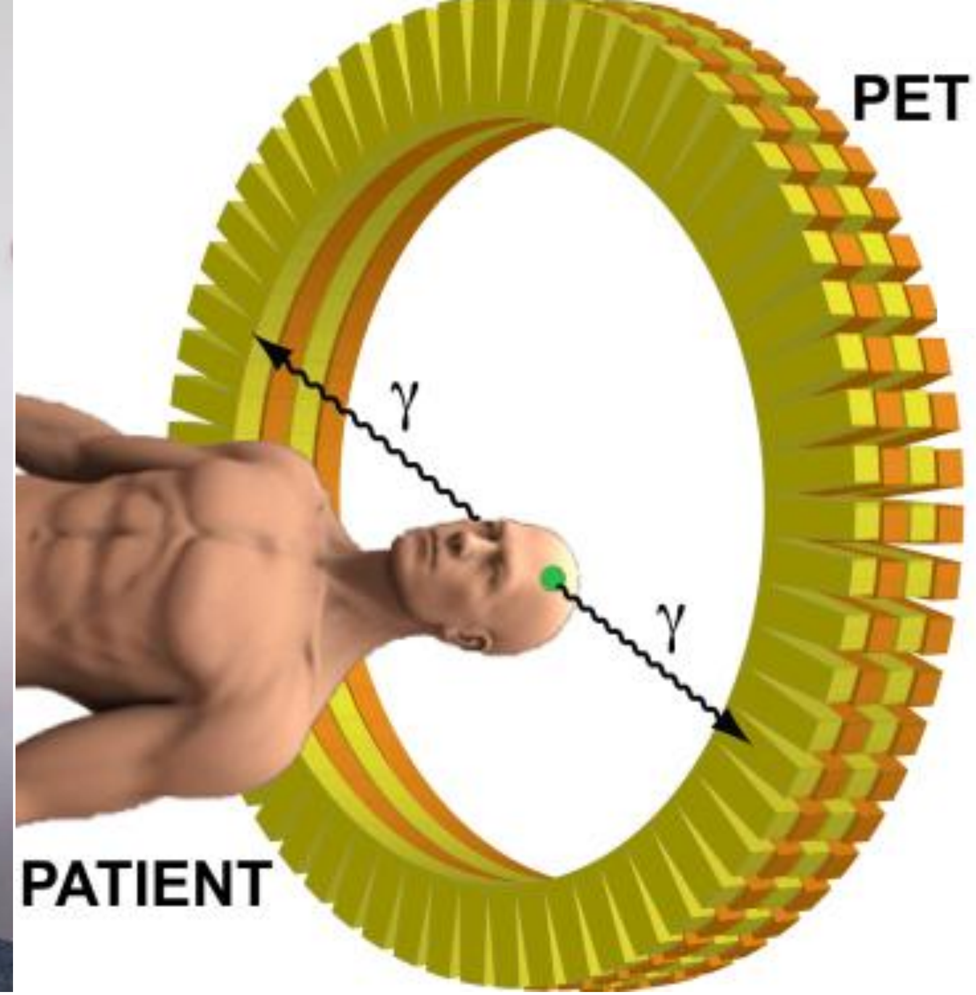


Jagiellonian **PET**

fizyka, bio-fizyka, medycyna

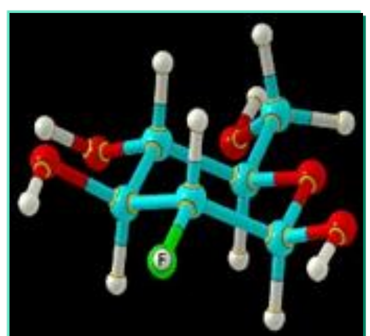
- materia -- anty-materia
- ciemny foton
- Jagielloński PET
- symetrie dyskretne
- **nano-struktura komórek**

Jagiellonian **PET**



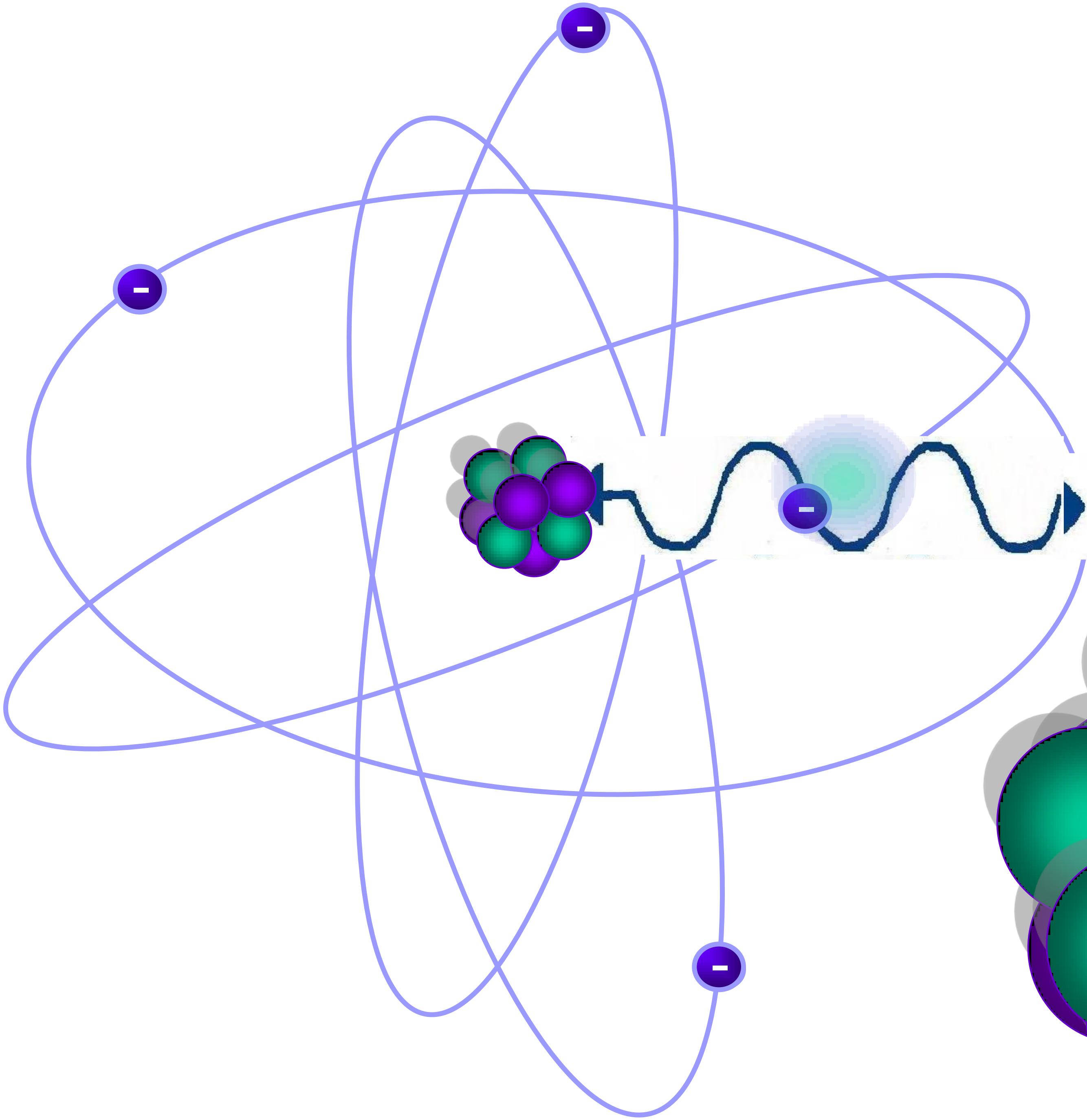
RADIOAKTYWNY CUKIER

Fluoro–deoksy-glukoza
(F-18 FDG)

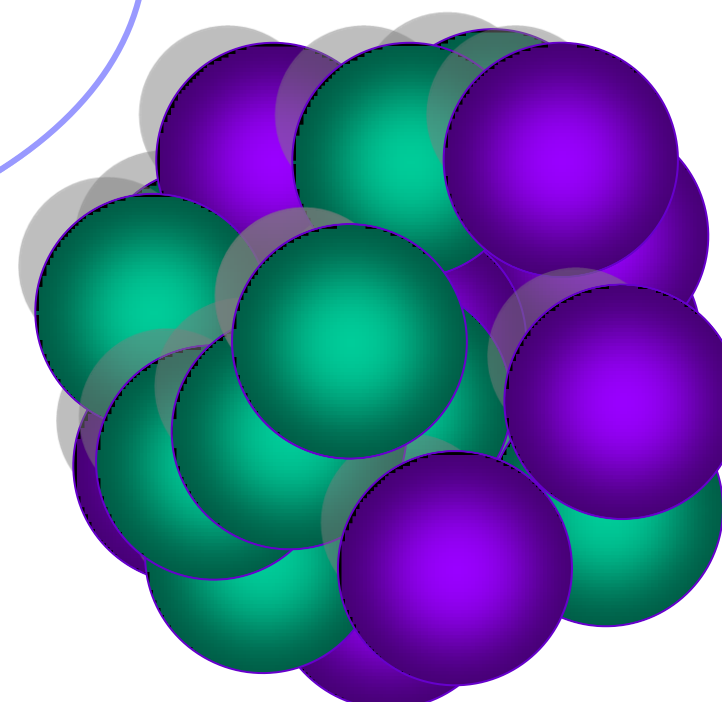


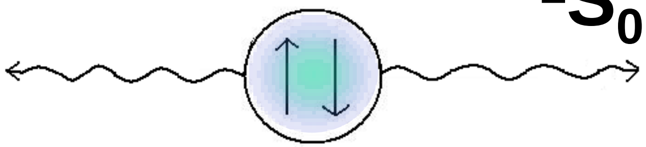
~200 000 000

kwantów gamma na sekunde

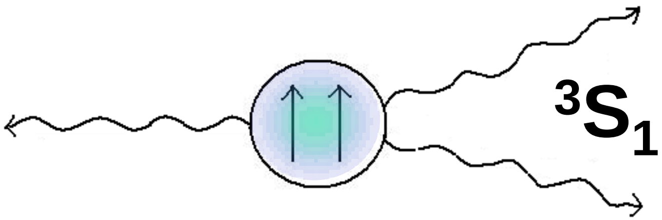


$$^{18}F \longrightarrow {}^{18}O + e^{+} + \nu_e$$





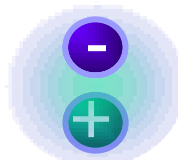
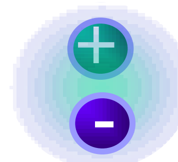
$^{1}S_{0}$ **Para-positronium tau(p-Ps) ≈ 125 ps**

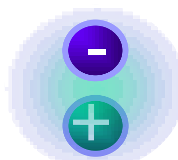
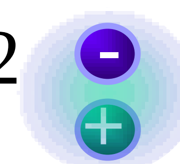


$^{3}S_{1}$ **Ortho-positronium tau(o-Ps) ≈ 142 ns**

	$^{1}S_{0}$	$^{3}S_{1}$
L	0	0

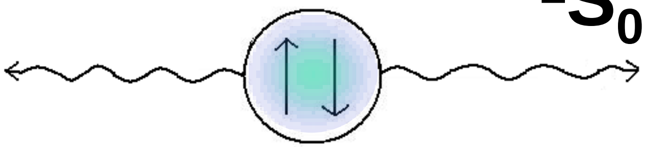
parzystość ładunkowa C

C  $=$ α 

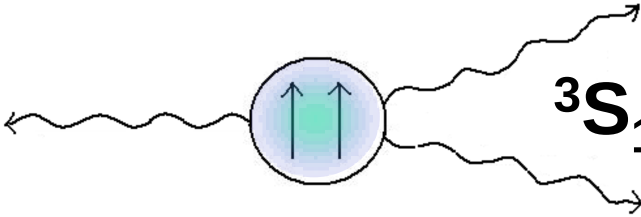
$C\,C$  $= C\,\alpha$  $= \alpha^2$ 

$$\alpha^2 = 1$$

$$\alpha = +1 \text{ or } \alpha = -1$$



$^1S_0$ **Para-positronium tau(p-Ps) ≈ 125 ps**



$^3S_1$ **Ortho-positronium tau(o-Ps) ≈ 142 ns**

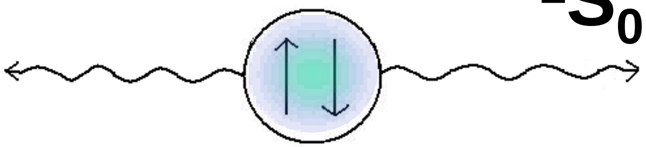
	$^1S_0$	$^3S_1$
L	0	0
S	0	1
C	+	-

S = 0 $\downarrow\uparrow - \uparrow\downarrow$

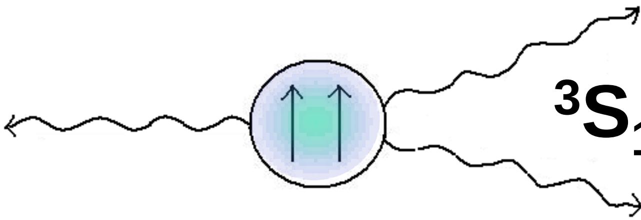
S = 1 $\uparrow\uparrow + \downarrow\downarrow$

$$C\,|Ps> = (-1)^{L+S}\,|Ps>$$

$$C\,|n\gamma> = (-1)^{n}\,|\,n\gamma>$$



$^1S_0$ **Para-positronium tau(p-Ps) ≈ 125 ps**



$^3S_1$ **Ortho-positronium tau(o-Ps) ≈ 142 ns**

		$^1S_0$	$^3S_1$
	L	0	0
	S	0	1
	C	+	-
L=0 ->	P	-	-
	CP	-	+

S = 0 $\quad \downarrow\uparrow - \uparrow\downarrow$

S = 1 $\quad \uparrow\uparrow + \downarrow\downarrow$

$$C\,|Ps> = (-1)^{L+S}\,|Ps>$$

$$C\,|n\gamma> = (-1)^{n}\;|\,n\gamma>$$

Eigen-state of Hamiltonian and P, C, CP operators

The lightest known atom and at the same time anti-atom which undergoes self-annihilation as flavor neutral mesons

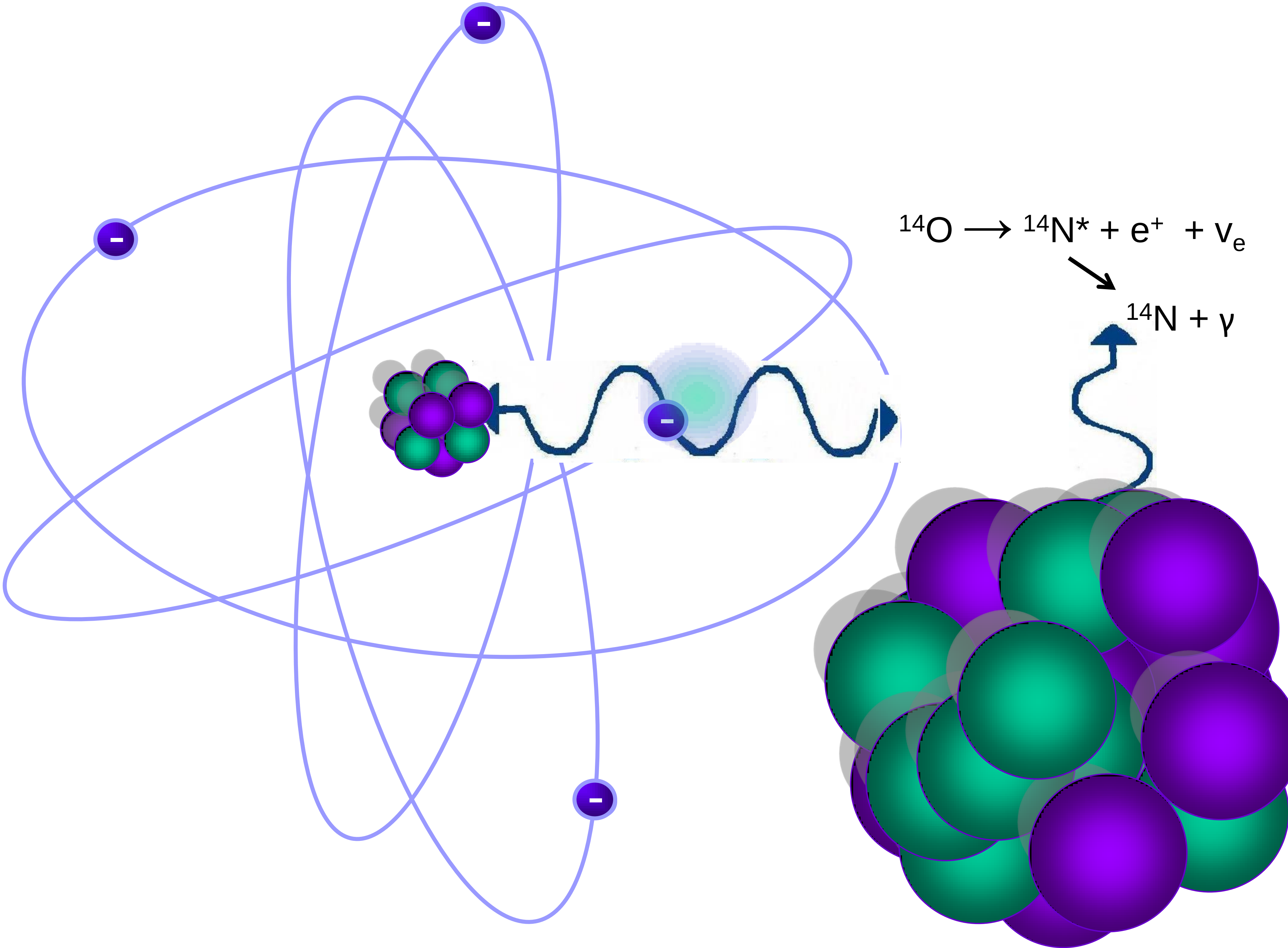
The simplest atomic system with charge conjugation aigenstates.

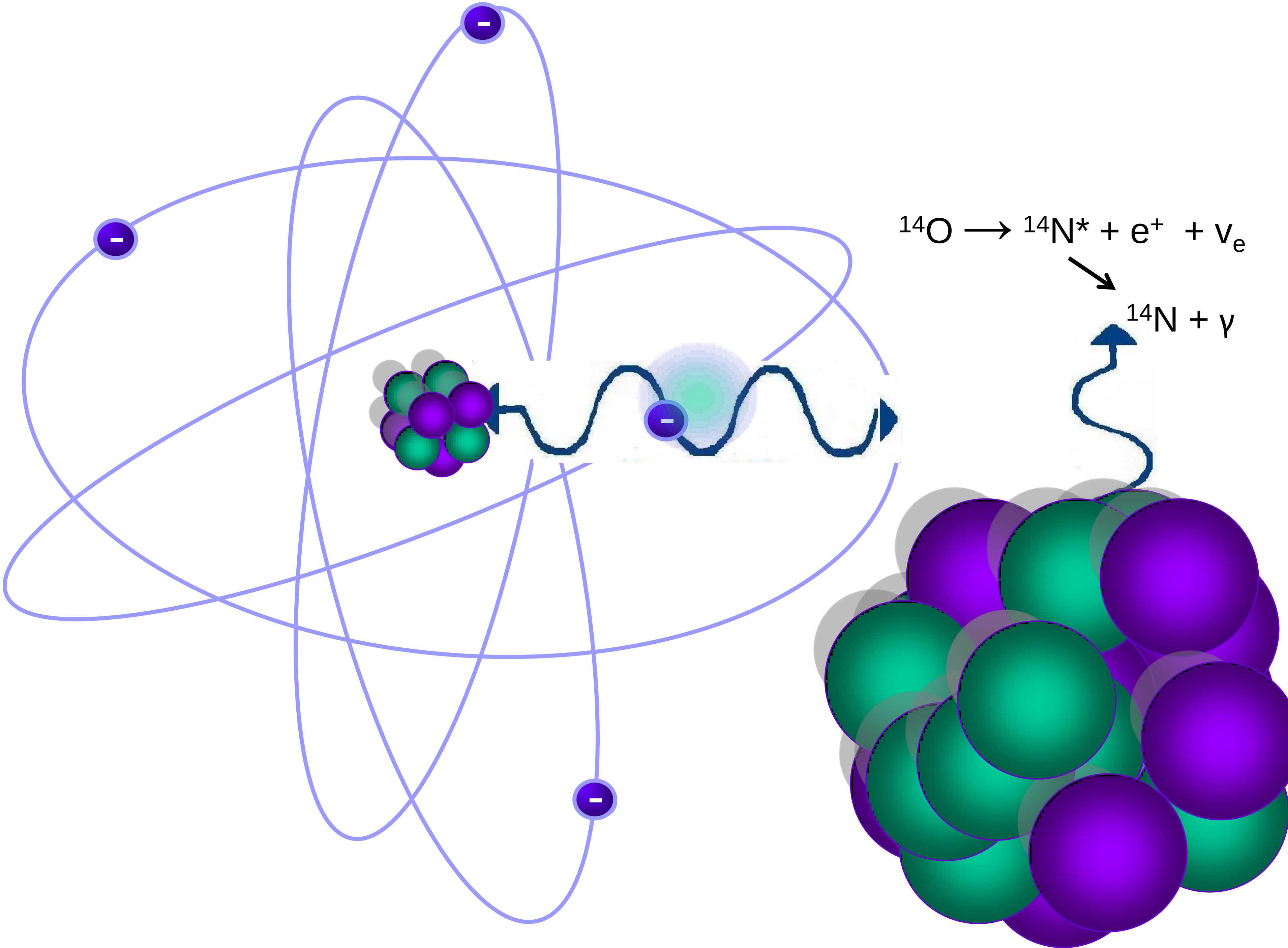
Electrons and positron are the lightest leptons so they can not decay into lighter partilces via weak interactiom ..

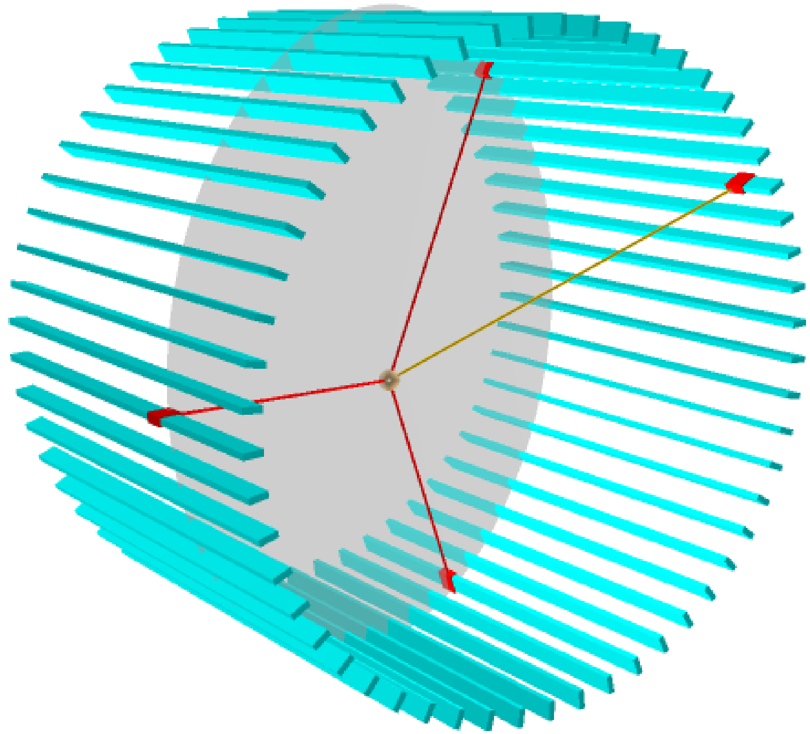
No charged particles in the final state (radiative corrections very small 2 * 10^{-10})
Light by light contributions to various correlations are small
B. K. Arbic et al., Phys. Rev. A 37, 3189 (1988).
W. Bernreuther et al., Z. Phys. C 41, 143 (1988).

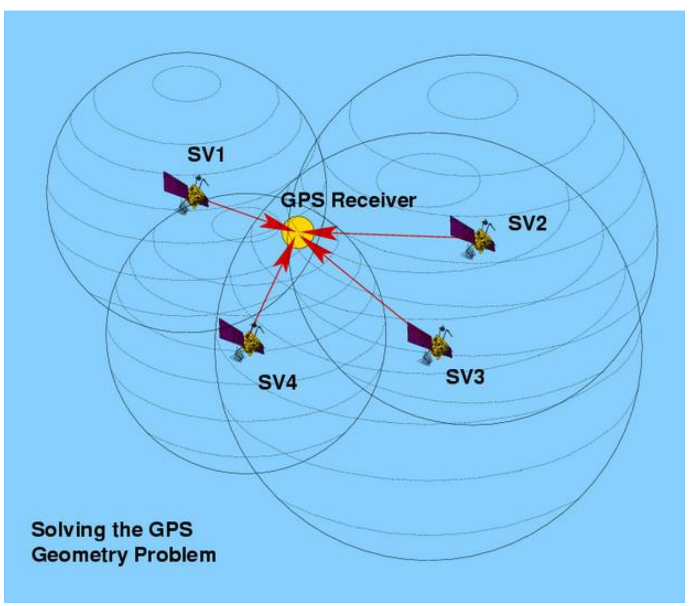
Purely Leptonic state !

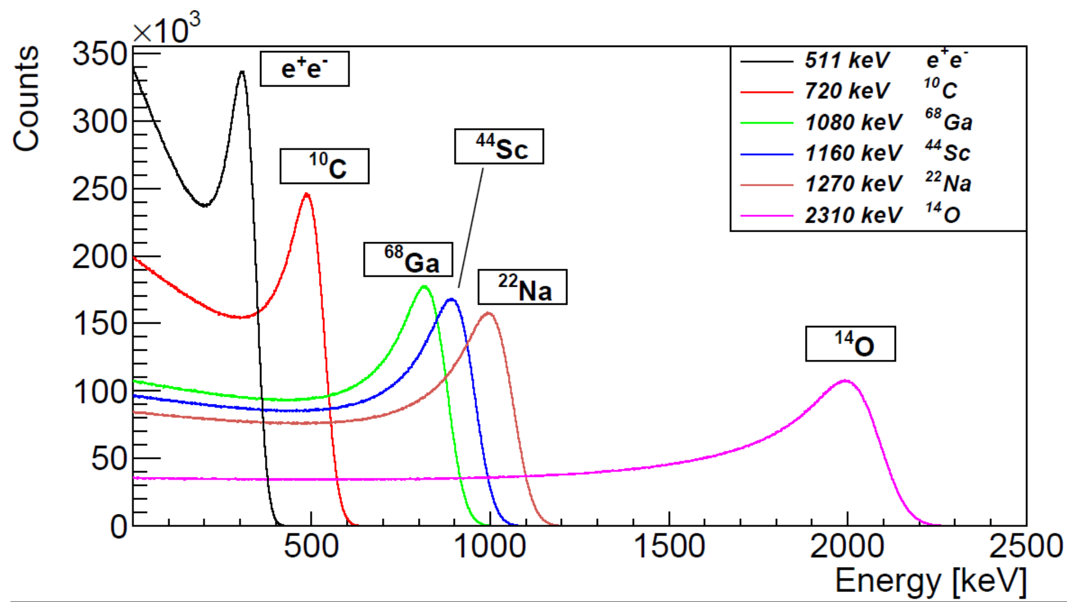
Breaking of P, T, C, CP, observed but only for processes involving quarks
So far breaking of these symmetries was not observed for purely leptonic systems.

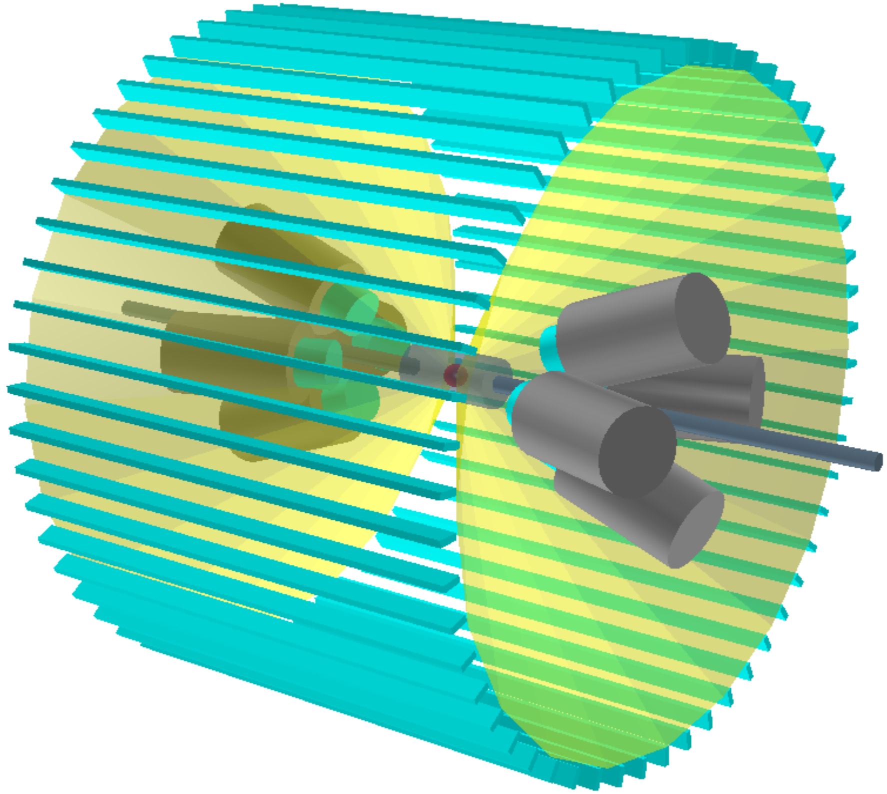

$^{14}O \longrightarrow {}^{14}N^{*} + e^{+} + \nu_e$
$^{14}N + \gamma$

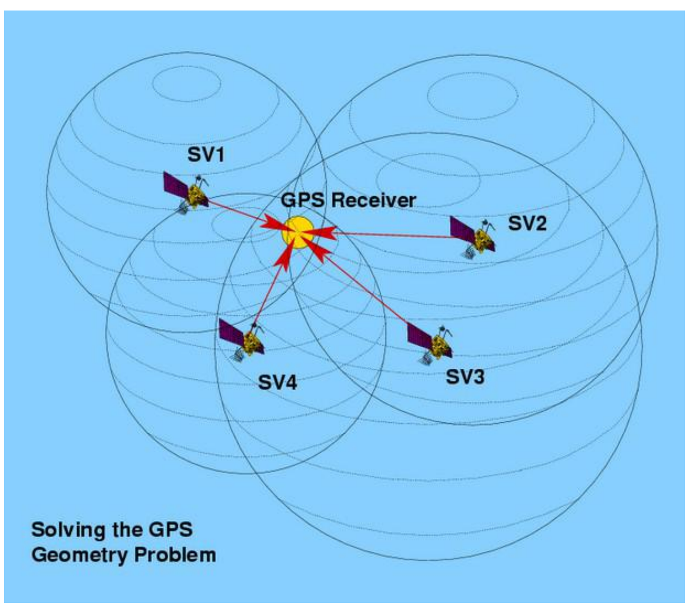

$^{14}O \longrightarrow {}^{14}N^* + e^+ + \nu_e$
$^{14}N + \gamma$

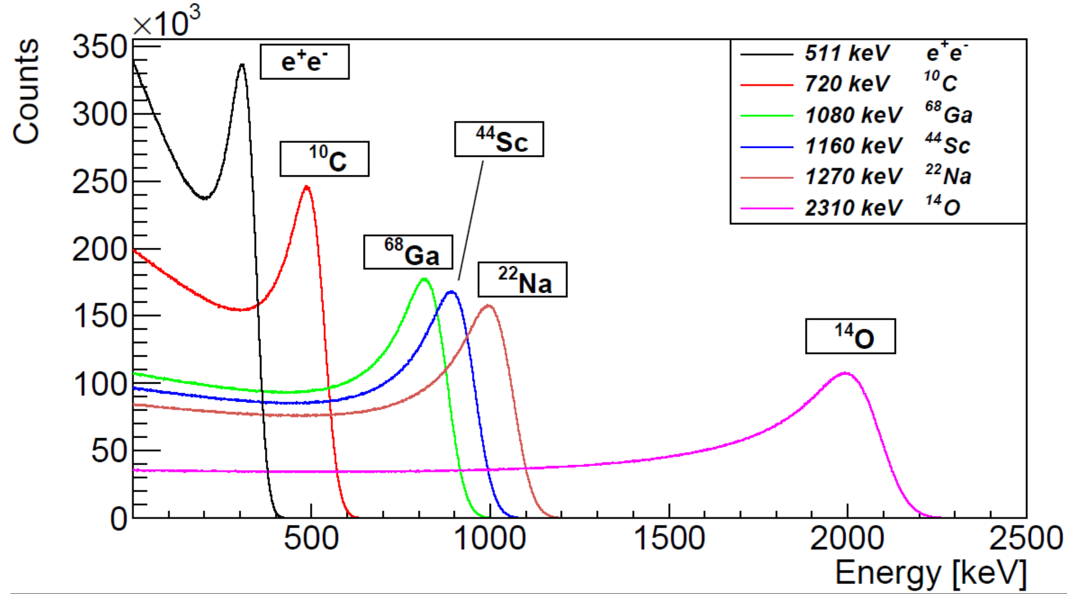


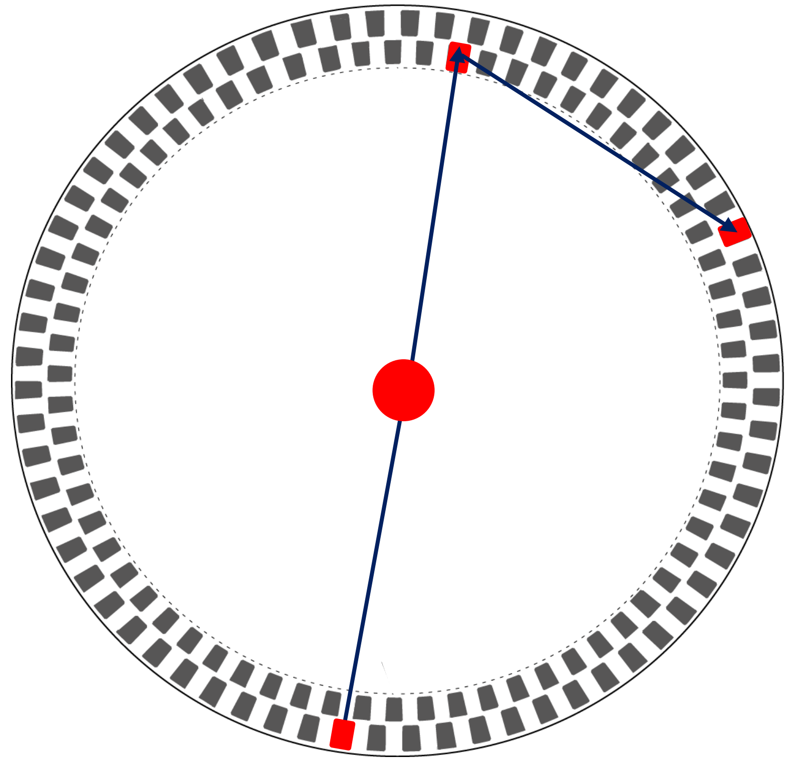

SV1
GPS Receiver
SV2
SV4
SV3
Solving the GPS
Geometry Problem


×10^3
Counts
Energy [keV]
e+e-
10C
44Sc
68Ga
22Na
14O
511 keV e+e-
720 keV 10C
1080 keV 68Ga
1160 keV 44Sc
1270 keV 22Na
2310 keV 14O

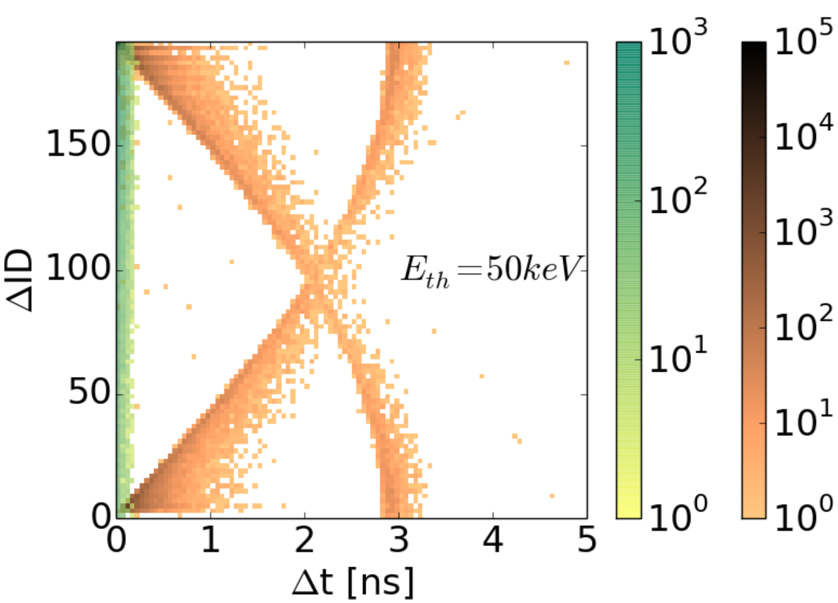


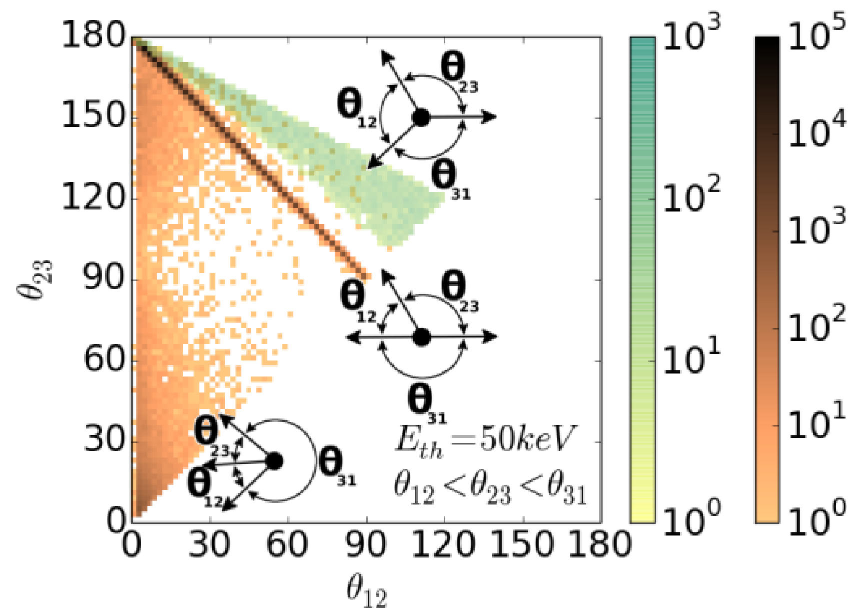

SV1
GPS Receiver
SV2
SV4
SV3
Solving the GPS
Geometry Problem

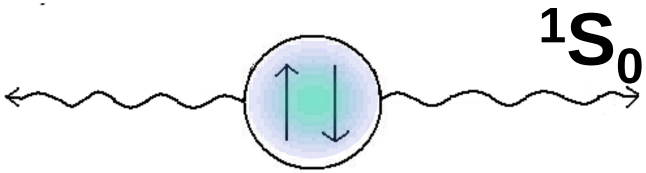

×10^3
Counts
350
300
250
200
150
100
50
0
500
1000
1500
2000
2500
Energy [keV]
e+e-
10C
68Ga
44Sc
22Na
14O
511 keV e+e-
720 keV 10C
1080 keV 68Ga
1160 keV 44Sc
1270 keV 22Na
2310 keV 14O



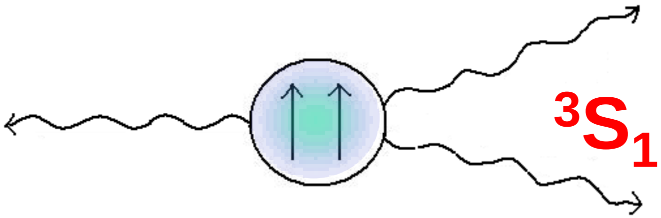
Reduction by factor 10^9







$^1S_0$ **Para-positronium tau(p-Ps) ≈ 125 ps**



$^3S_1$ **Ortho-positronium tau(o-Ps) ≈ 142 ns**

	$^1S_0$	$^3S_1$	2γ	3γ	4γ	5γ	...
C	+	-	+	-	+	-	

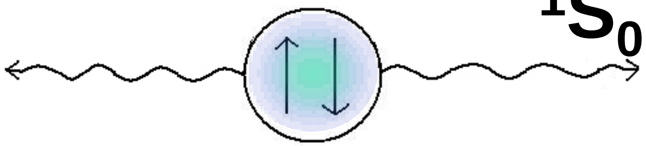
bound state mixing is not possible because there are
no positronium states with opposite *C*-parity and the same J^P.

BR ($^3S_1 \to 4\gamma$ / $^3S_1 \to 3\gamma$) $< 2.6\ 10^{-6}$ at 90%CL

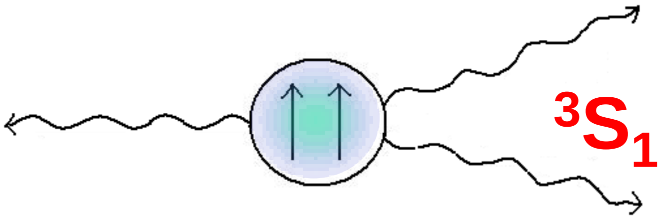
J. Yang et al., Phys. Rev. A54 (1996) 1952

BR ($^1S_0 \to 3\gamma$ / $^1S_0 \to 2\gamma$) $< 2.8\ 10^{-6}$ at 68%CL

A. P. Mills and S. Berko, Phys. Rev. Lett. 18 (1967) 420



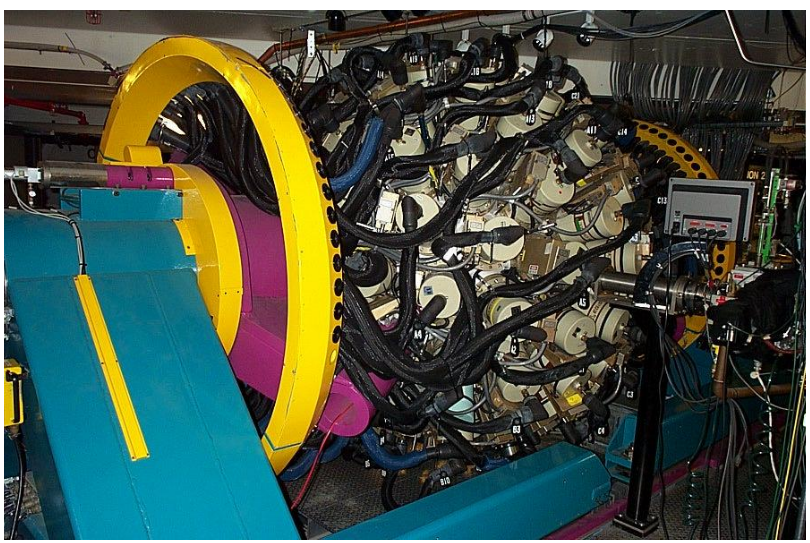
$^1S_0$ **Para-positronium tau(p-Ps) ≈ 125 ps**

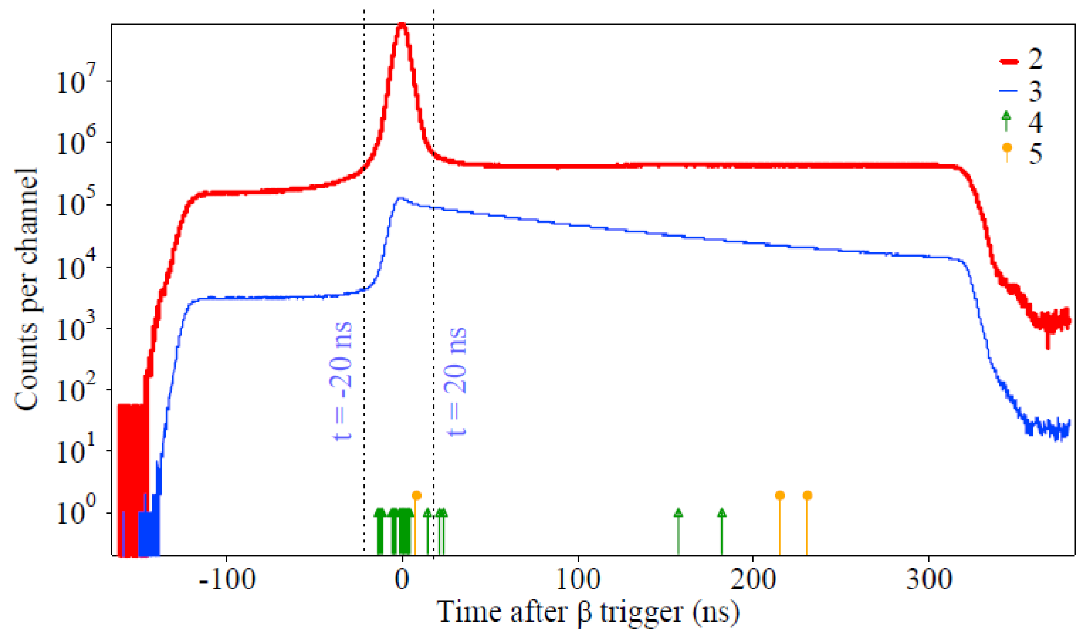


$^3S_1$ **Ortho-positronium tau(o-Ps) ≈ 142 ns**

BR ($^1S_0$ --> 5γ / $^1S_0$ --> 2γ) < 2.7 10^{-7} at 90%CL

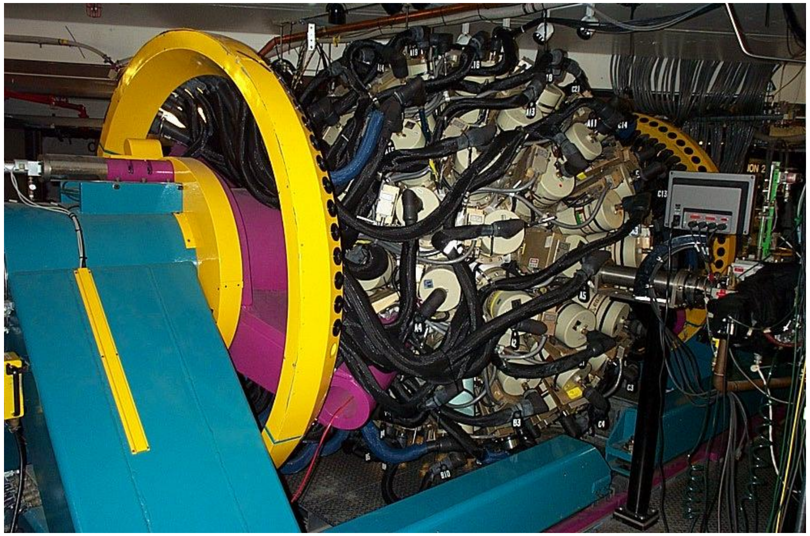
P. A. Vetter and S. J. Freedman Phys. Rev. A 66 (2002) 052505

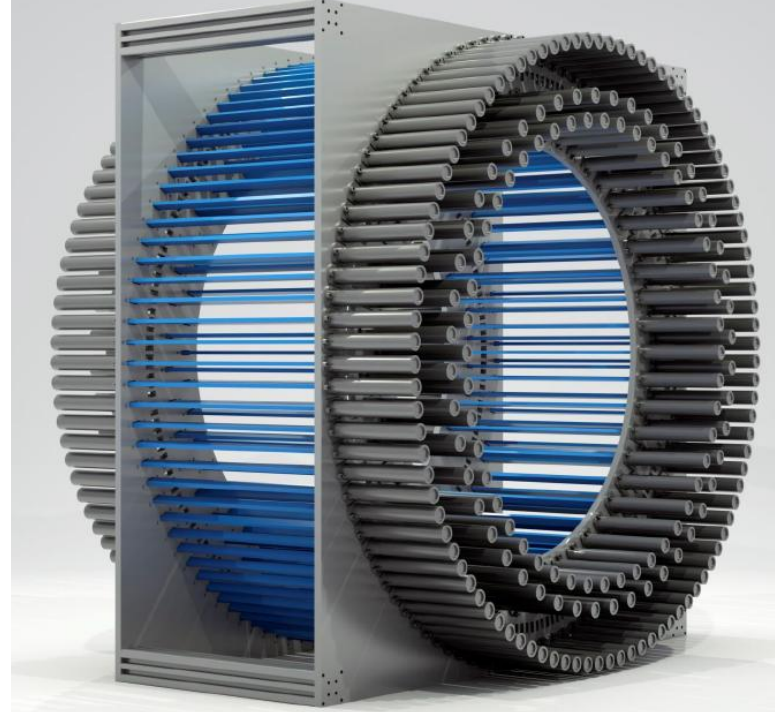




Result from: P. A. Vetter and S. J. Freedman Phys. Rev. A 66 (2002) 052505

Figure taken form the presentation of A. O. Macchiavelli, Nuclear Structure, Oak Ridge, 2006





Sigma(Delta_T) > 4.6 ns

Sigma(Delta_T) < 0.1ns

$$N(\Delta t) = N_o^0\,(1+C\ldots)\,e^{-\Delta t/\tau o\text{-}Ps} \quad + \quad N_{direct}\,e^{-\Delta t/\tau b} + N_p^0\,(1+C\ldots)\,e^{-\Delta t/\tau p\text{-}Ps}$$

Efficiency + cuts 0.15 per gamma

Source activity 0.04 MBq

Acceptance x efficiency: 0.1 per gamma

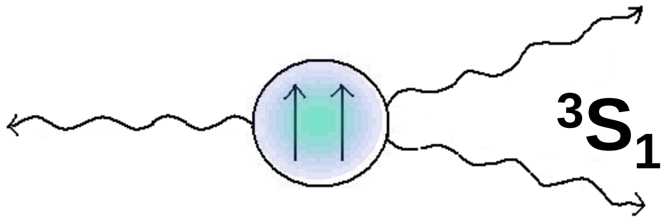
Activity > 20 MBq

pile-ups t_crystal / t_plastic_scintillator ~= 100

Angular resolution

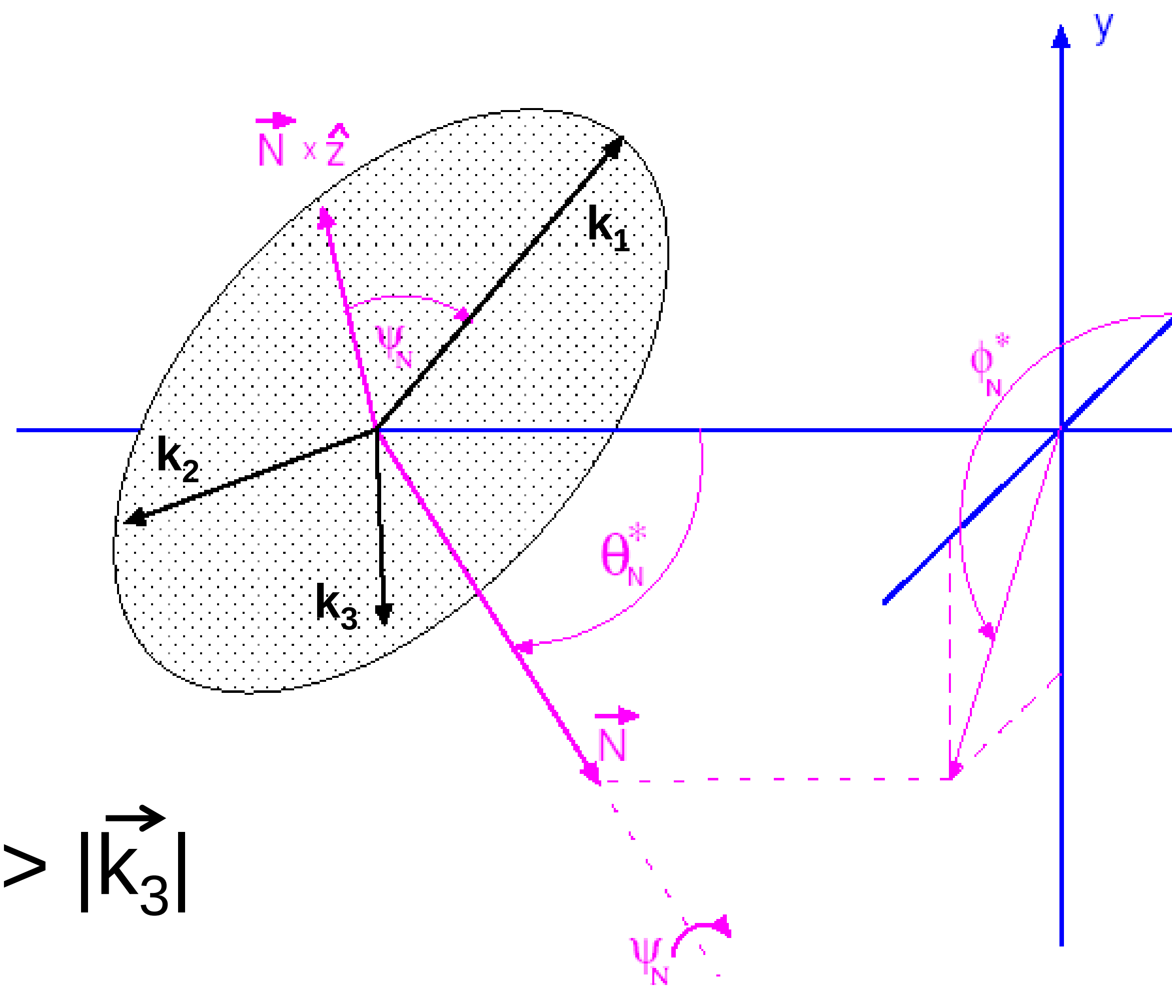
detector 7cm(dia) / 25cm (radius)

1cm / 40cm (radius)

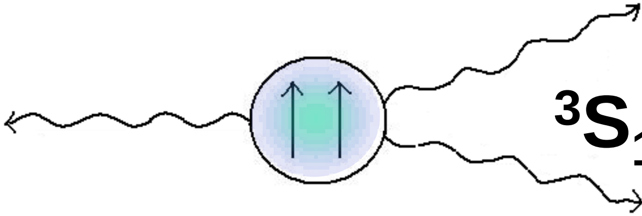


$^3S_1$ **Ortho-positronium tau(o-Ps) ≈ 142 ns**

Operator	C	P	T	CP	CPT
$\vec{S} \bullet \vec{k}_1 \times \vec{k}_2$	+	+	-	+	-



$$|\vec{k}_1| > |\vec{k}_2| > |\vec{k}_3|$$



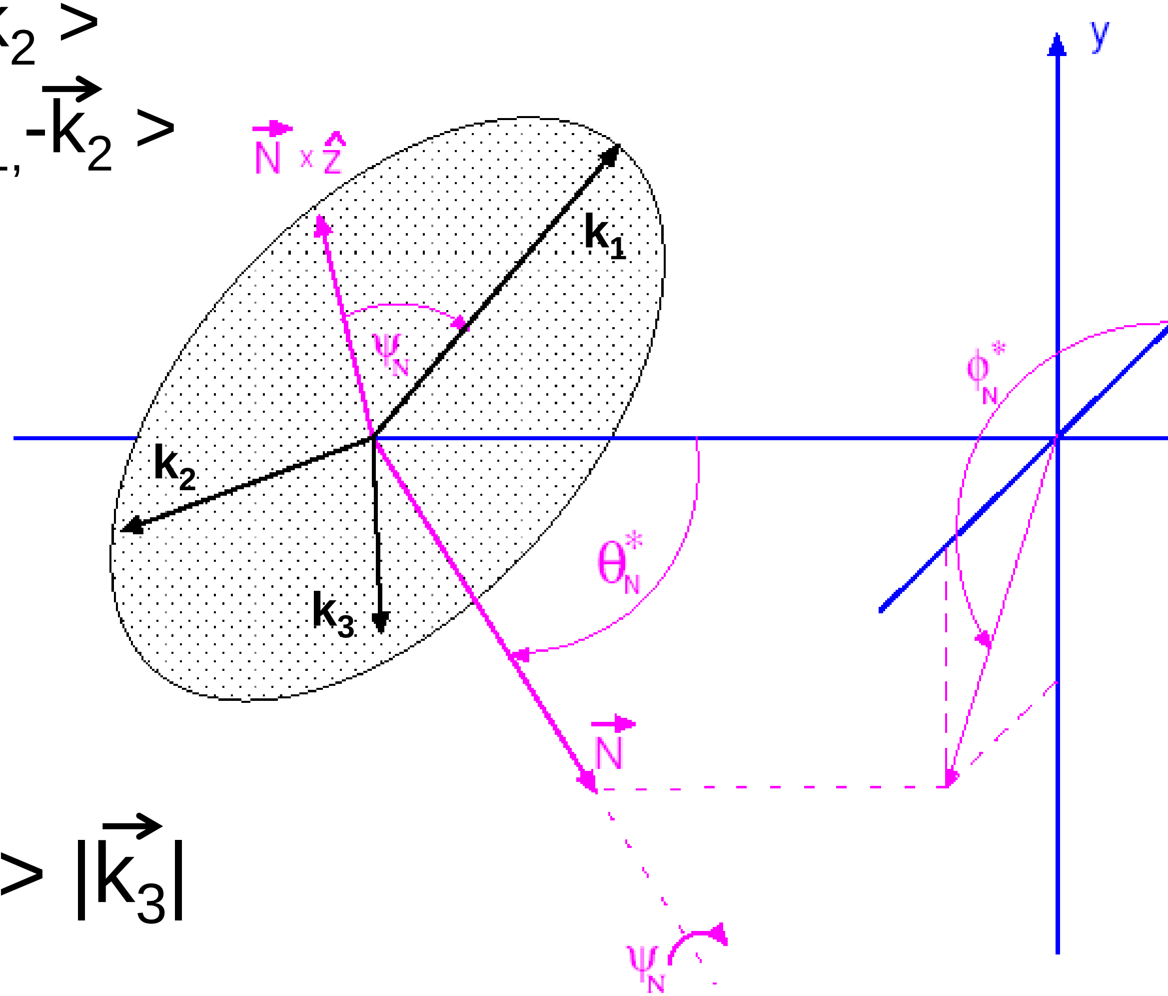
$^3S_1$ **Ortho-positronium tau(o-Ps) ≈ 142 ns**

Operator	C	P	T	CP	CPT
$O \equiv \vec{S} \bullet \vec{k}_1 \times \vec{k}_2$	+	+	-	+	-

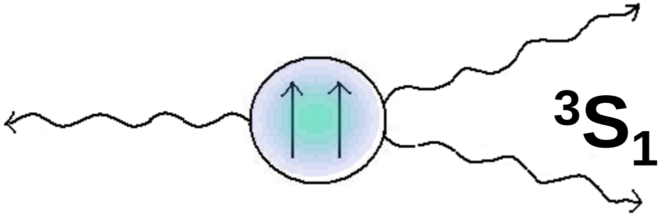
$$T\,|\vec{S},\vec{k}_1,\vec{k}_2 > \;= |-\vec{S},-\vec{k}_1,-\vec{k}_2 >$$

$$O|\vec{S},\vec{k}_1,\vec{k}_2 > = -\,O|-\vec{S},-\vec{k}_1,-\vec{k}_2 >$$

$$\sum\; O\,|\vec{S},\vec{k}_1,\vec{k}_2 > \;= 0$$



$$|\vec{k}_1| > |\vec{k}_2| > |\vec{k}_3|$$



$^3S_1$ Ortho-positronium tau(**o-Ps**) ≈ 142 ns

Operator	C	P	T	CP	CPT
$\vec{S} \cdot \vec{k}_1 \times \vec{k}_2$	+	+	-	+	-

P.A. Vetter and S.J. Freedman,
Phys. Rev. Lett. 91, 263401 (2003).

C_CPT = 0.0071 ± 0.0062

SM $10^{-10} – 10^{-9}$

photon-photon interactions

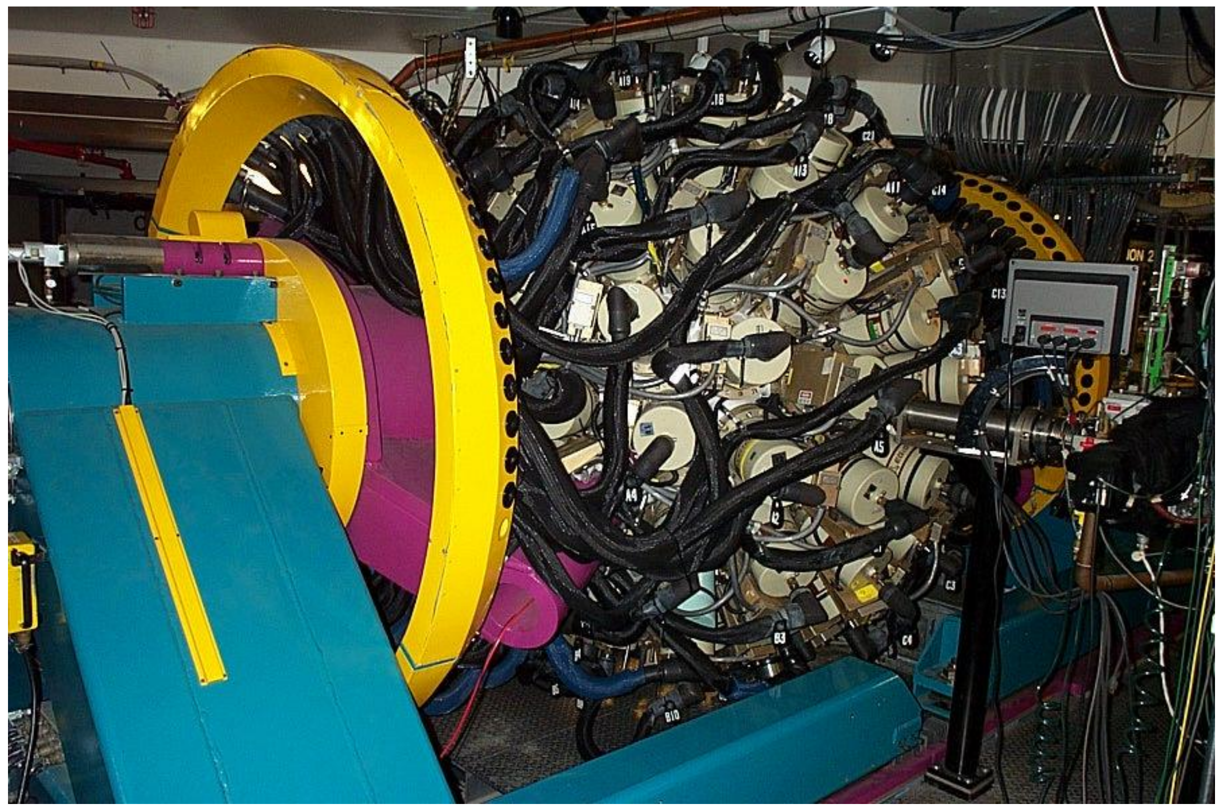
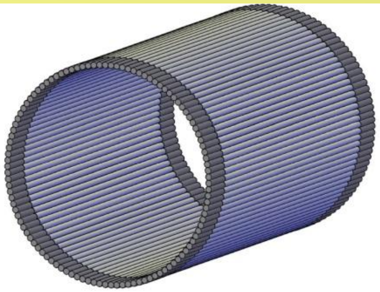
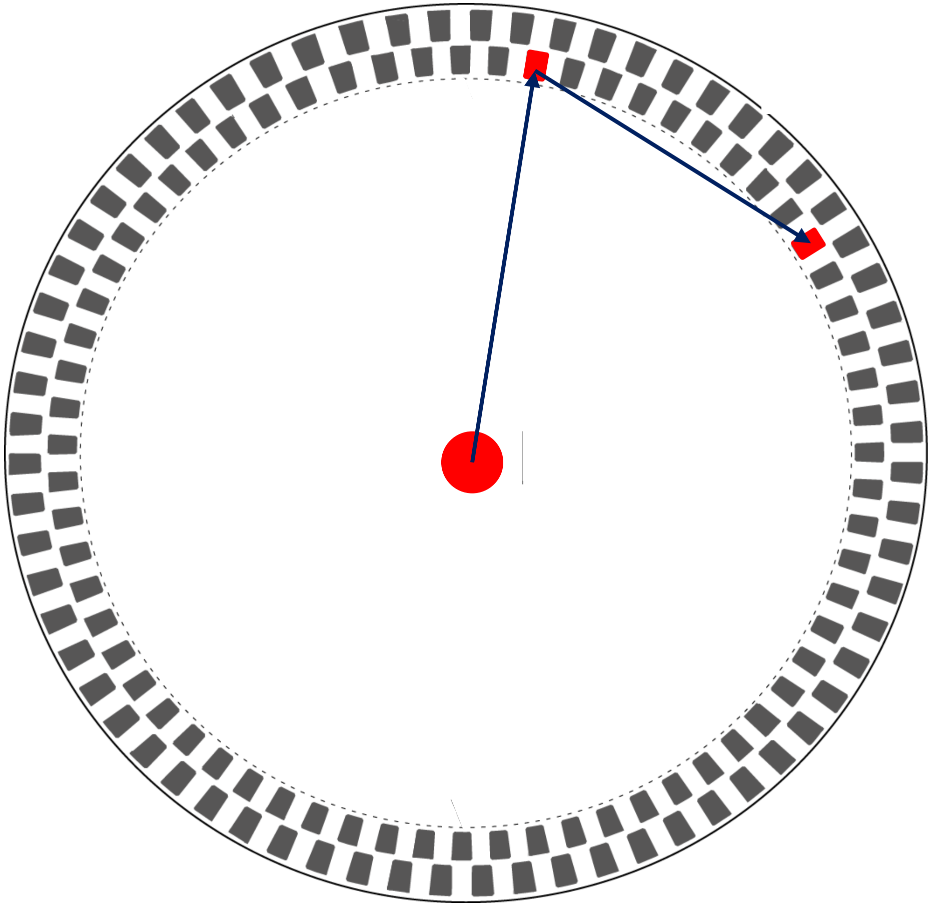


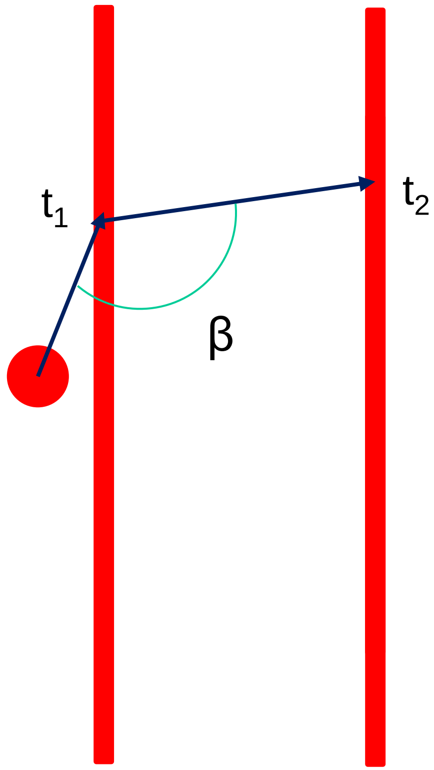
Figure taken form the presentation of P. Vetter, INT UW Seattle, November, 2002

J-PET --> polarization of γ



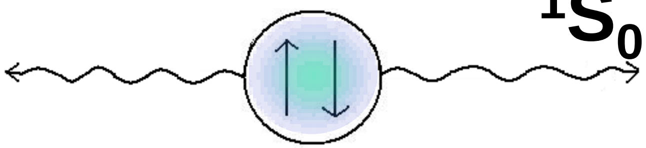
$\sigma(t_1 - t_2) < 100\text{ps}$



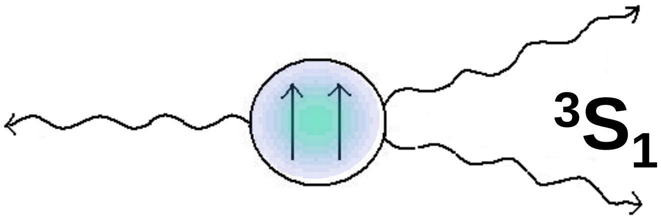


Compton scattering:

β correlated with $\vec{E}$

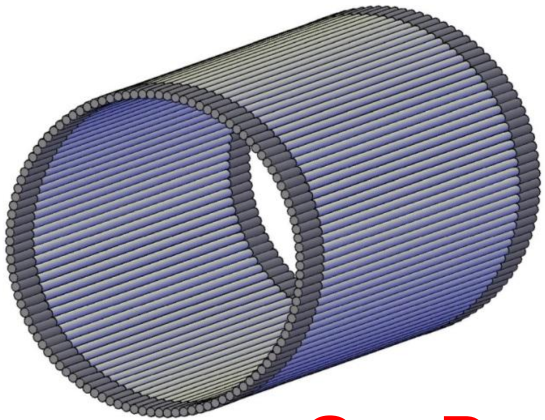


$^1S_0$ **Para-positronium tau(p-Ps) ≈ 125 ps**



$^3S_1$ **Ortho-positronium tau(o-Ps) ≈ 142 ns**

	T	P
$\vec{S}$	-	+
$\vec{k}$	-	-
$\vec{E}$	+	-



$^3S_1 \rightarrow 3\gamma$ -->

Operator	C	P	T	CP	CPT
$\vec{S} \cdot \vec{k}_1 \times \vec{k}_2$	+	+	-	+	-
$(\vec{S} \cdot \vec{k}_1)(\vec{S} \cdot \vec{k}_1 \times \vec{k}_2)$	+	-	-	-	+

$^1S_0 \rightarrow 2\gamma$ -->

Operator	C	P	T	CP	CPT
$\vec{S} \cdot \vec{E}_1 \times \vec{E}_2$	+	+	-	+	-
$\vec{S} \cdot \vec{E}_1$	+	-	-	-	+

fizyka, bio-fizyka, medycyna

- **materia -- anty-materia**
- **ciemny foton**
- **Jagielloński PET**
- **symetrie dyskretne**
- **nano-struktura komórek**

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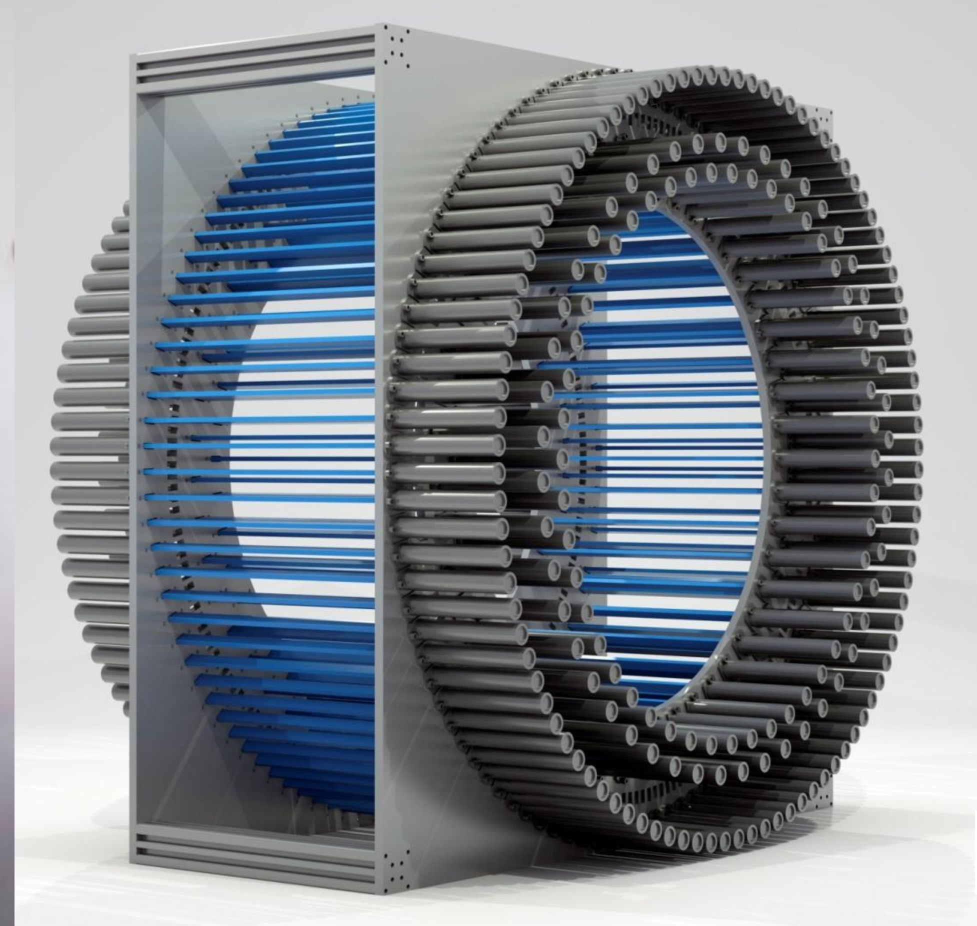

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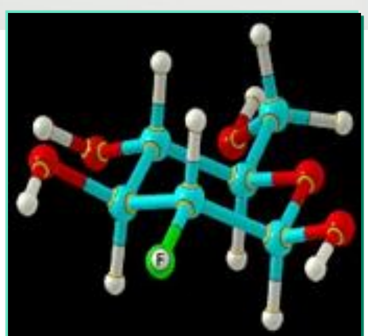
RADIOAKTYWNY CUKIER

Fluoro–deoksy-glukoza
(F-18 FDG)

~200 000 000
kwantów gamma na sekundę



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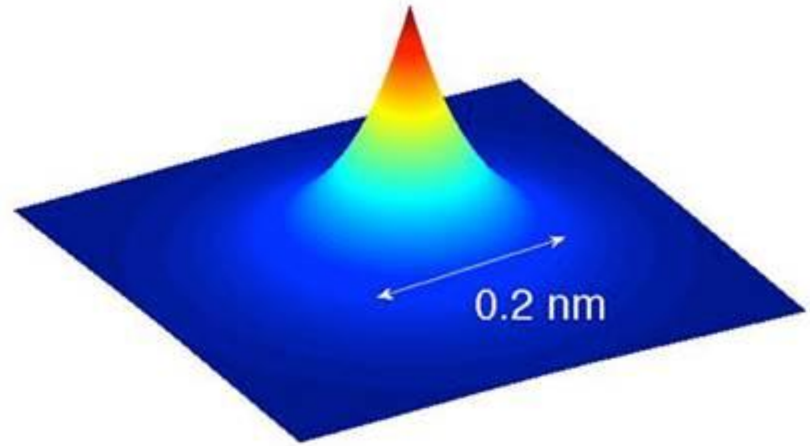
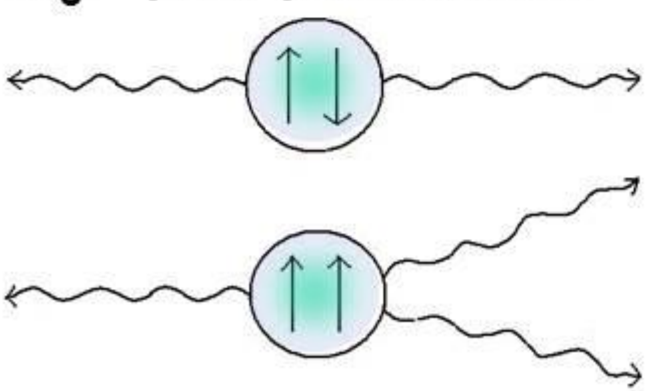
positronium



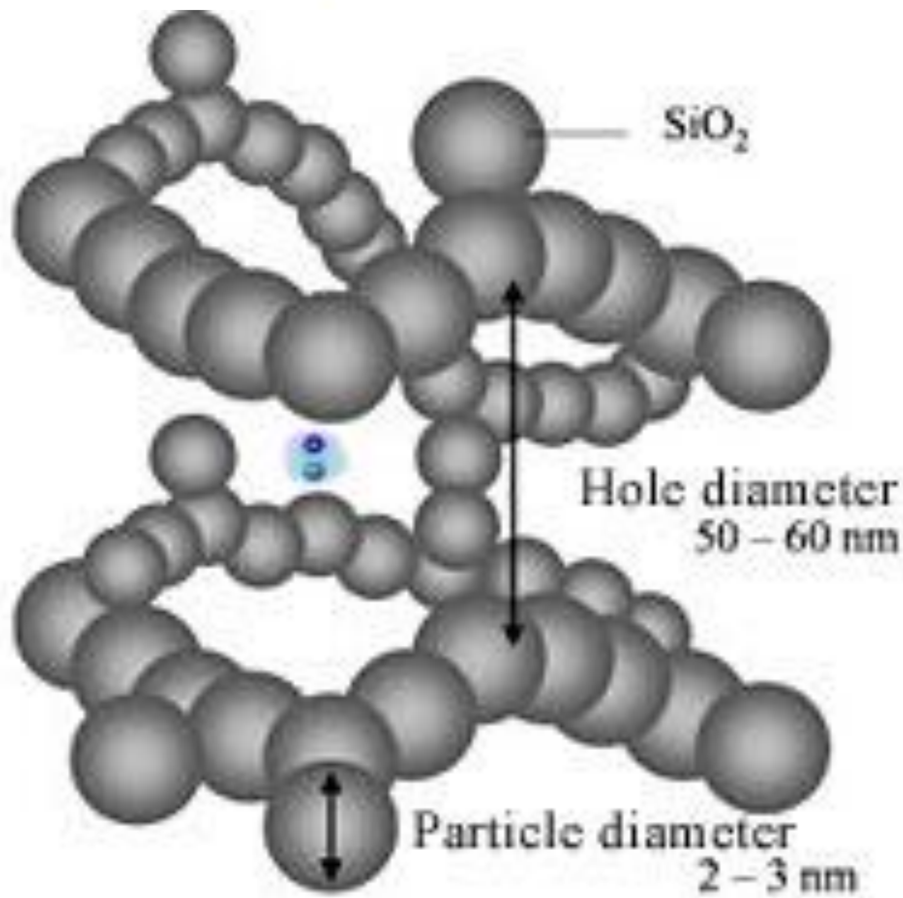
$\tau \approx 125$ ps

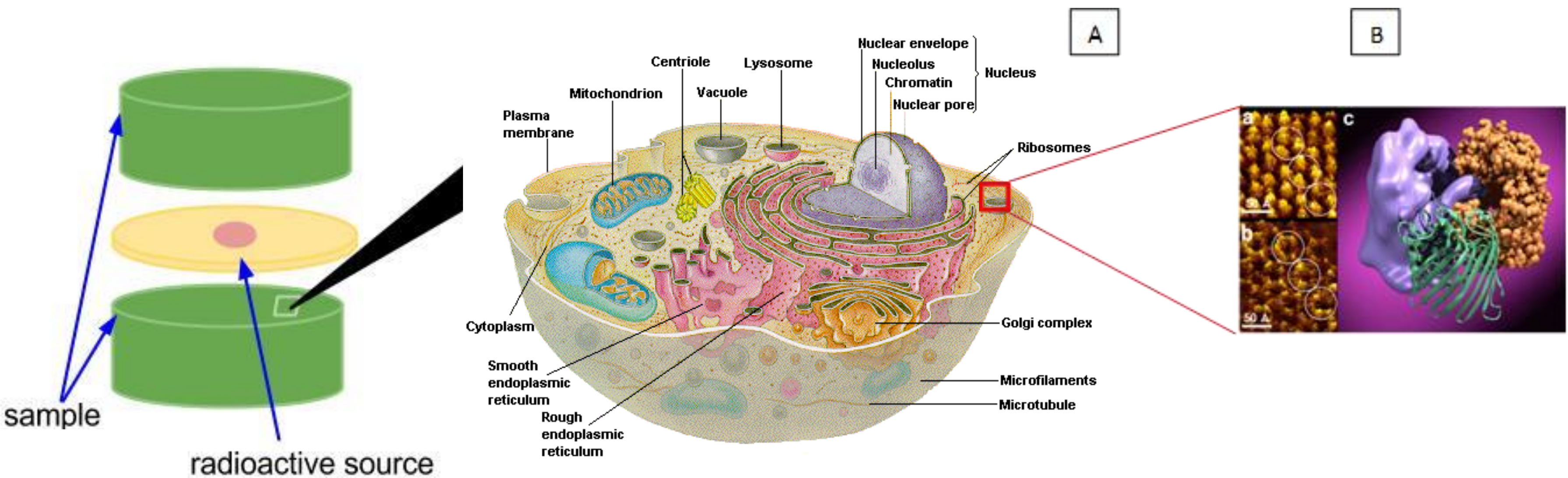
$^1S_0$ para-positronium



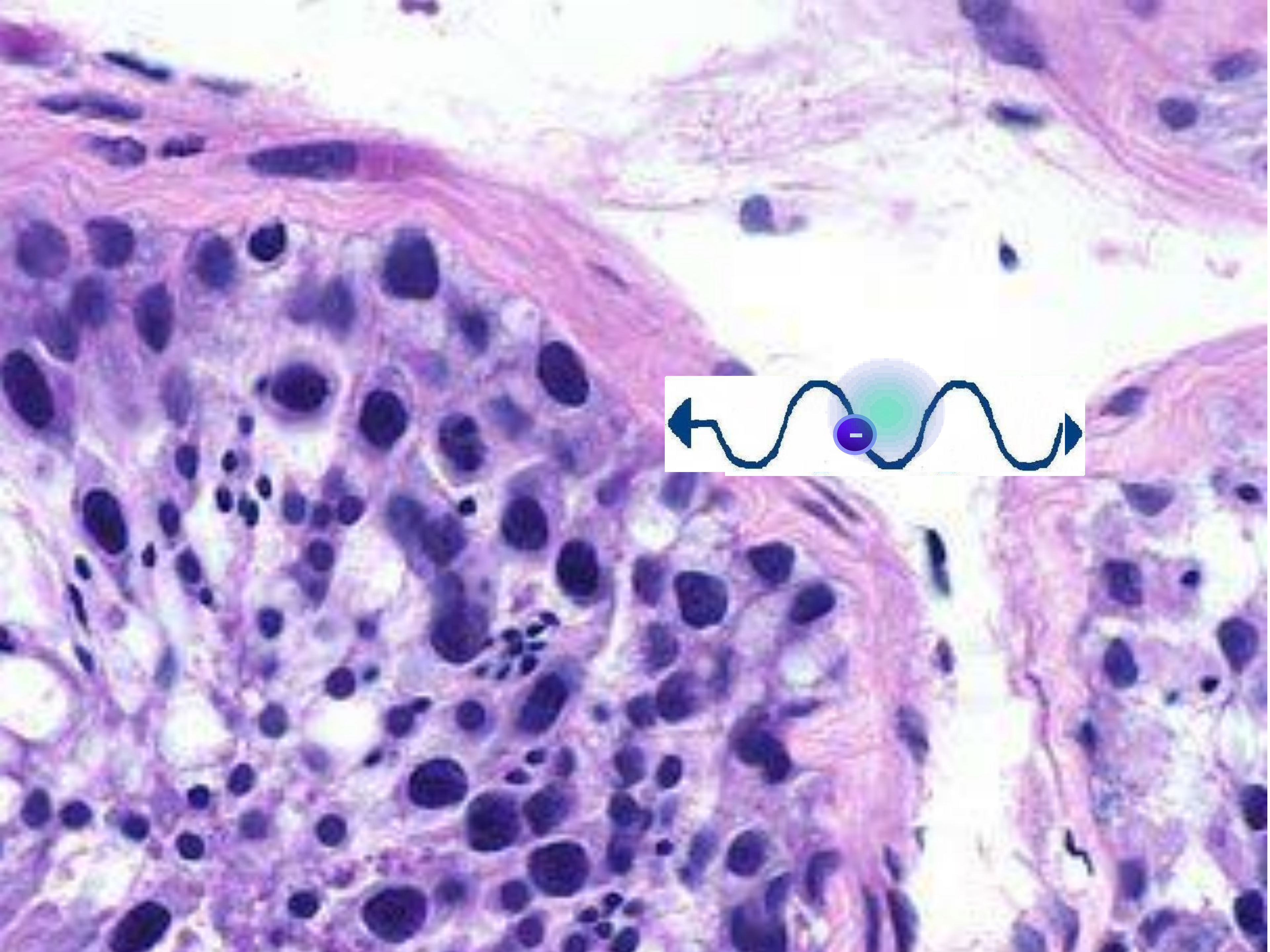
$^3S_1$ ortho-positronium

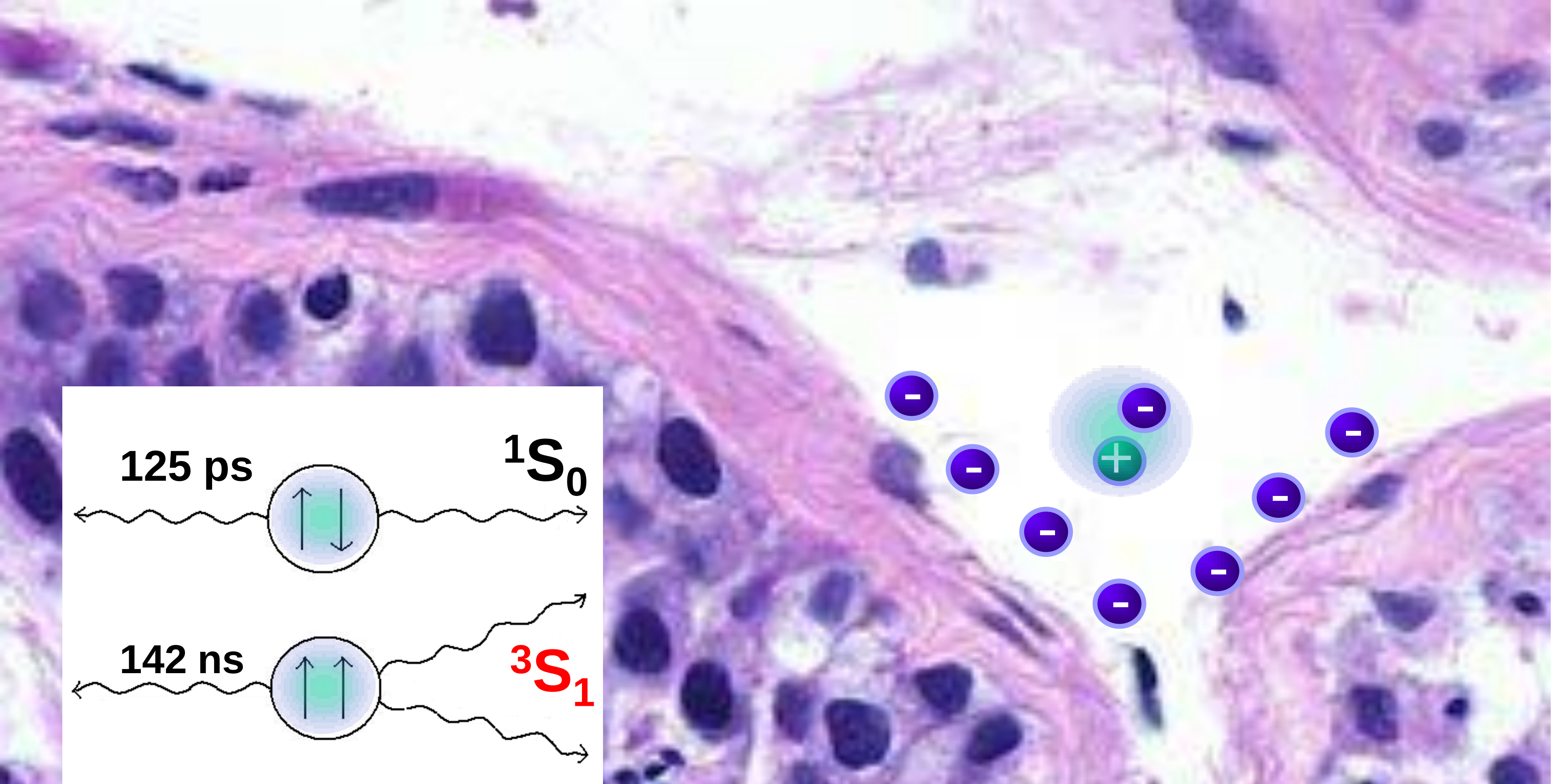
$\tau \approx 142$ ns





sample
radioactive source
A
B
Centriole
Lysosome
Nuclear envelope
Nucleolus
Chromatin
Nuclear pore
Nucleus
Mitochondrion
Vacuole
Plasma membrane
Ribosomes
Cytoplasm
Golgi complex
Smooth endoplasmic reticulum
Rough endoplasmic reticulum
Microfilaments
Microtubule
a
b
c
50 Å





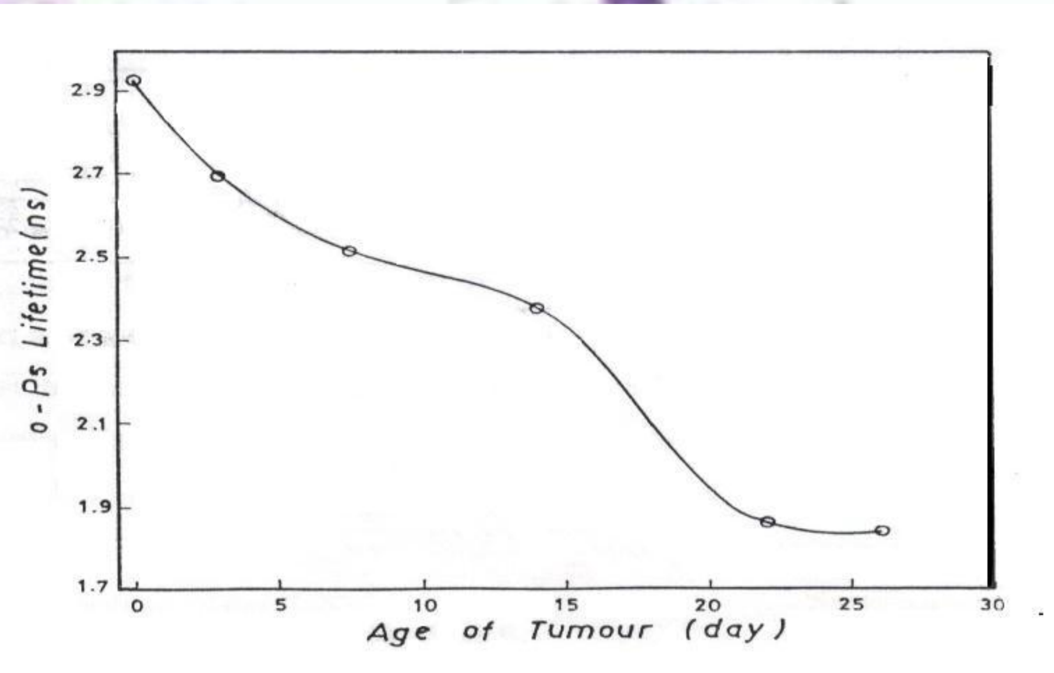
M_0 = mM/(M+m)

$E = E_H/2$ = 6.8 eV;

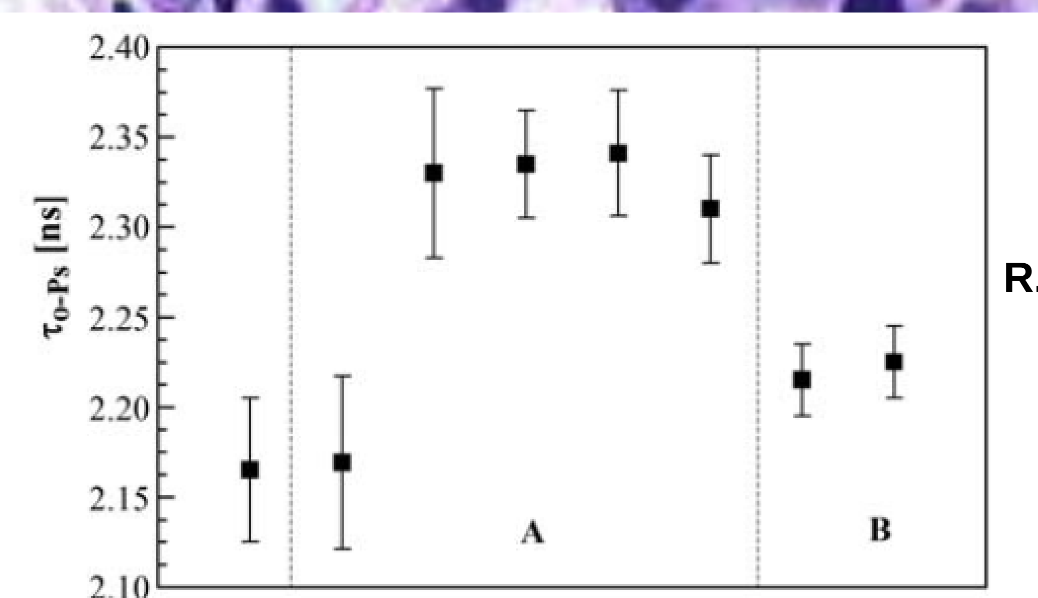
Radius = 2 r_B = 0.1 nm

(hyperfine splitting) 8.4×10^{-4} eV

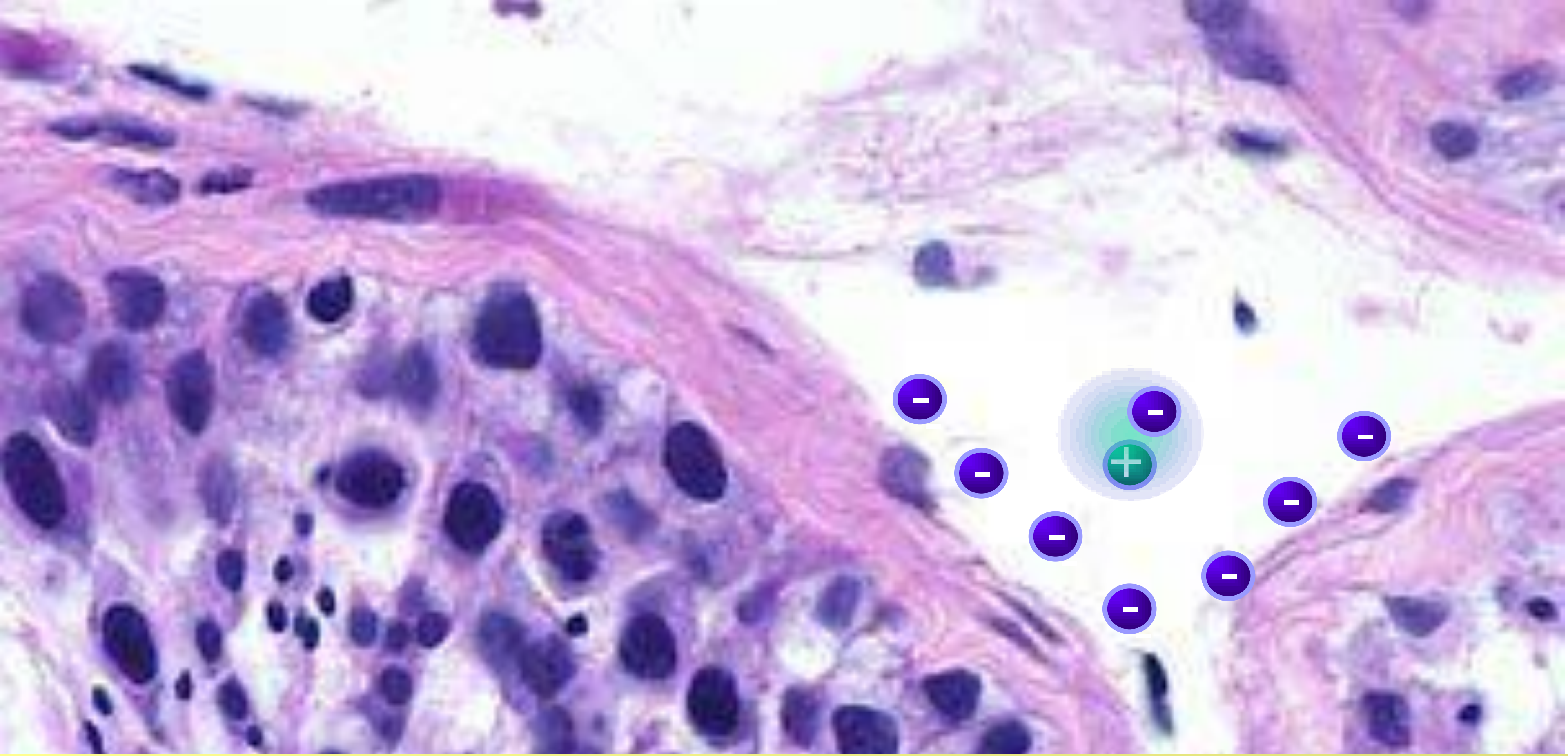
Patent application: **Morphometric imaging PCT/EP2014/068374 (2014)**



The age of mice's tumour with o-Ps lifetime
A.H. Al-Mashhadani et al., Iraqi J. Sci. 42C, 60 (2001) 3.



R. Pietrzak et al., NUKLEONIKA 58 (2013) 199



$$N(\Delta t) = N_o P_{ps} \tfrac{3}{4} e^{-\Delta t/\tau_{o\text{-}Ps}} + N_0 \tfrac{1}{4} P_{ps} e^{-\Delta t/\tau_{p\text{-}Ps}} + N_0 (1-P_{ps}) e^{-\Delta t/\tau_b}$$

$$(\tau_{o\text{-}Ps} \cdot P_{poz})^{-1} \quad W = SUV / (\tau_{o\text{-}Ps} \cdot P_{poz})$$

Patent application:

Morphometric imaging PCT/EP2014/068374 (2013)

J-PET for medicine, physics and biology

DZIĘKUJĘ PAŃSTWU ZA UWAGĘ

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