Development of Slow Positron Beam lines and Applications

Nagendra Nath Mondal

Department of Physics, Techno India Batanagar (Techno India Group), Kolkata 700141, West Bengal, India.

Ex- Doctoral & JSPS Postdoctoral research fellow @ Tokyo Metropolitan University, Tokyo, Japan.

Visiting Scientists @ SINP, @VECC, @ IIEST Kolkata, India.

nn.mondal2011@gmail.com, nagendra.n.mondal@biemsindia.org

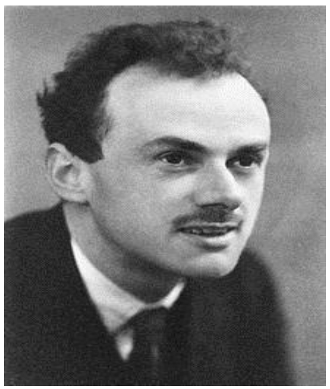
Outline of the Talk

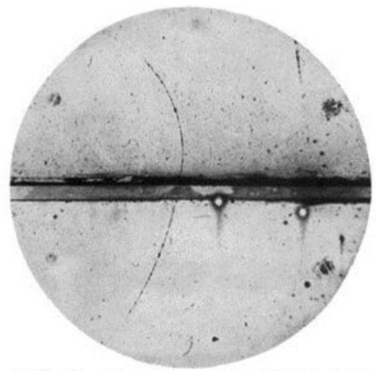
- Positron
- Slow Positron beam
- Slow positron beam facilities over the world
- Applications in different branches of Science
- Fundamental Research with Positron beams
- Production of high intense positron beam
- Detection of Positronium Bose-Einstein Condensation.

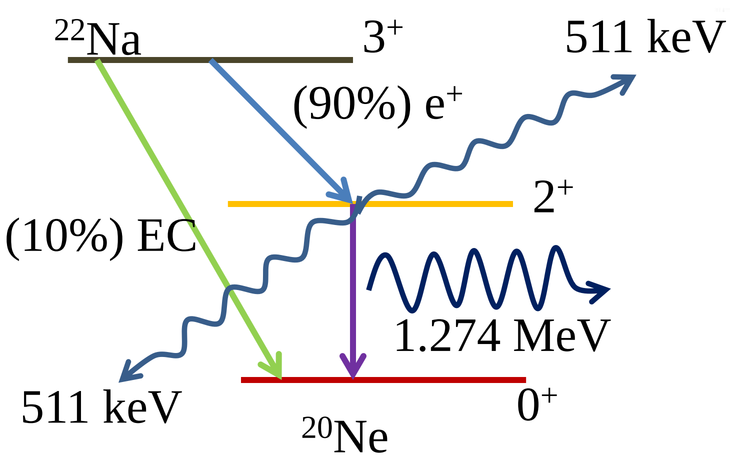
1. Positron

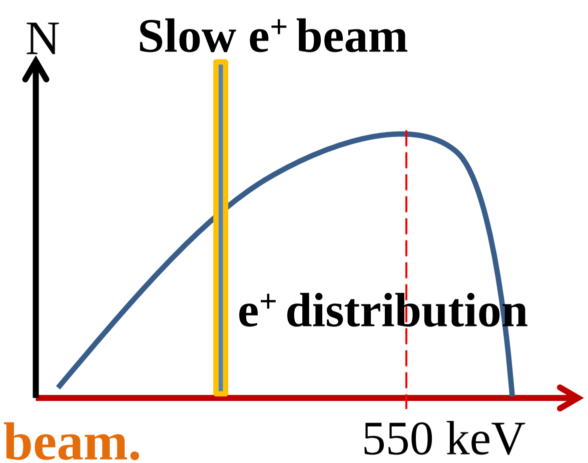
- Predicted by P. A. M. Dirac and Experimentally found by Carl Anderson in a Historic Cloud Chamber Experiment in 1932.
- β^{+}-decay process in Radio Isotope:

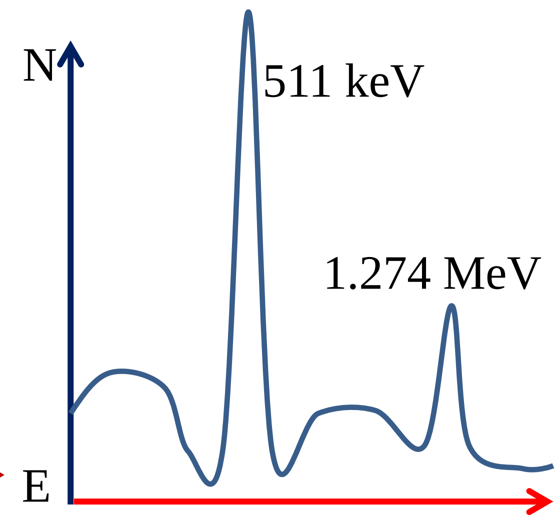
$$p \rightarrow n + e^{+} + \nu$$







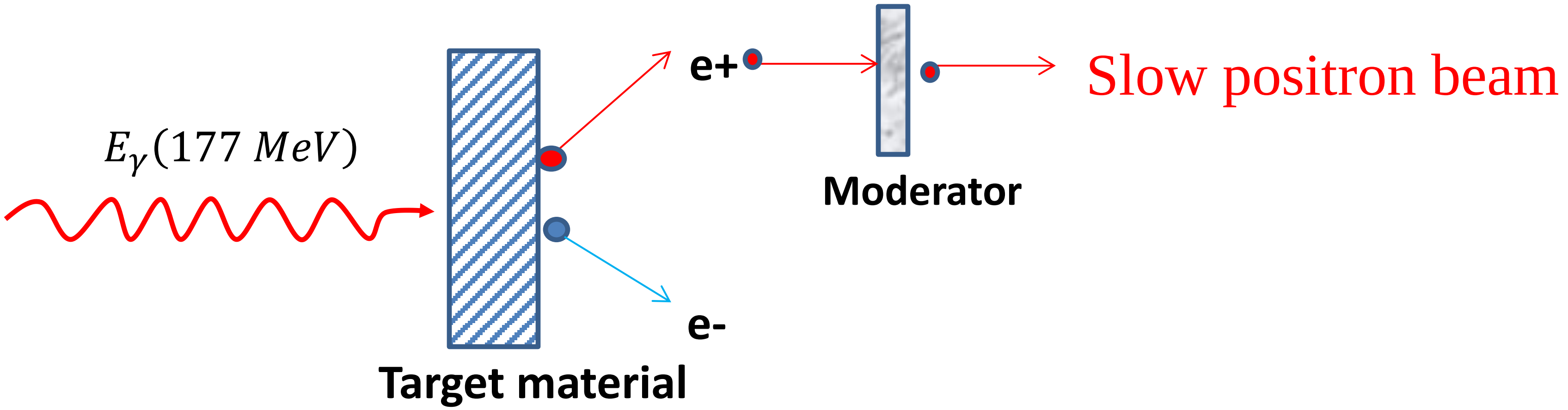




Half-life 2.6 Y, Good for slow e^{+} beam.

Fission reaction in Atomic Reactor:

- $^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3\,n + E_{\gamma}(177\ MeV)$



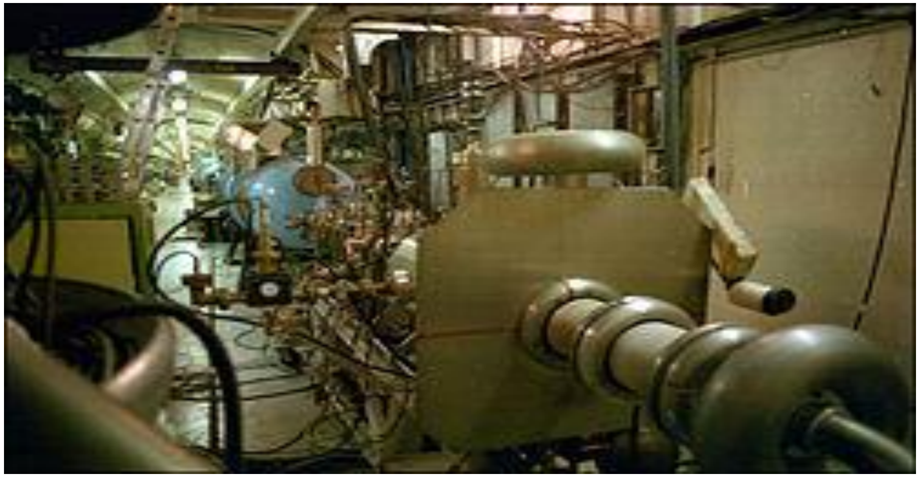
Fusion Reaction in the Stars/reactor:

$$^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + \boldsymbol{e^{+}} + \nu + 0.42\ MeV$$

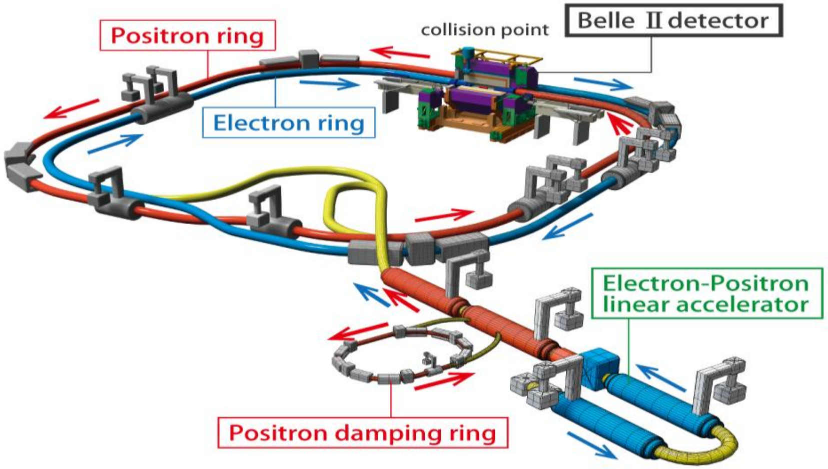
$$^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He + \boldsymbol{\gamma} + \mathbf{5.49}\ MeV$$

$$^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2{}^{1}_{1}H + 12.86\ MeV$$

2. Accelerator based e^+ Source



The Stanford University superconducting linear accelerator, housed on campus below the Hansen Labs until 2007. This facility is separate from SLAC



KEK in Japan, Photon Factory e^+, e^- beam lines

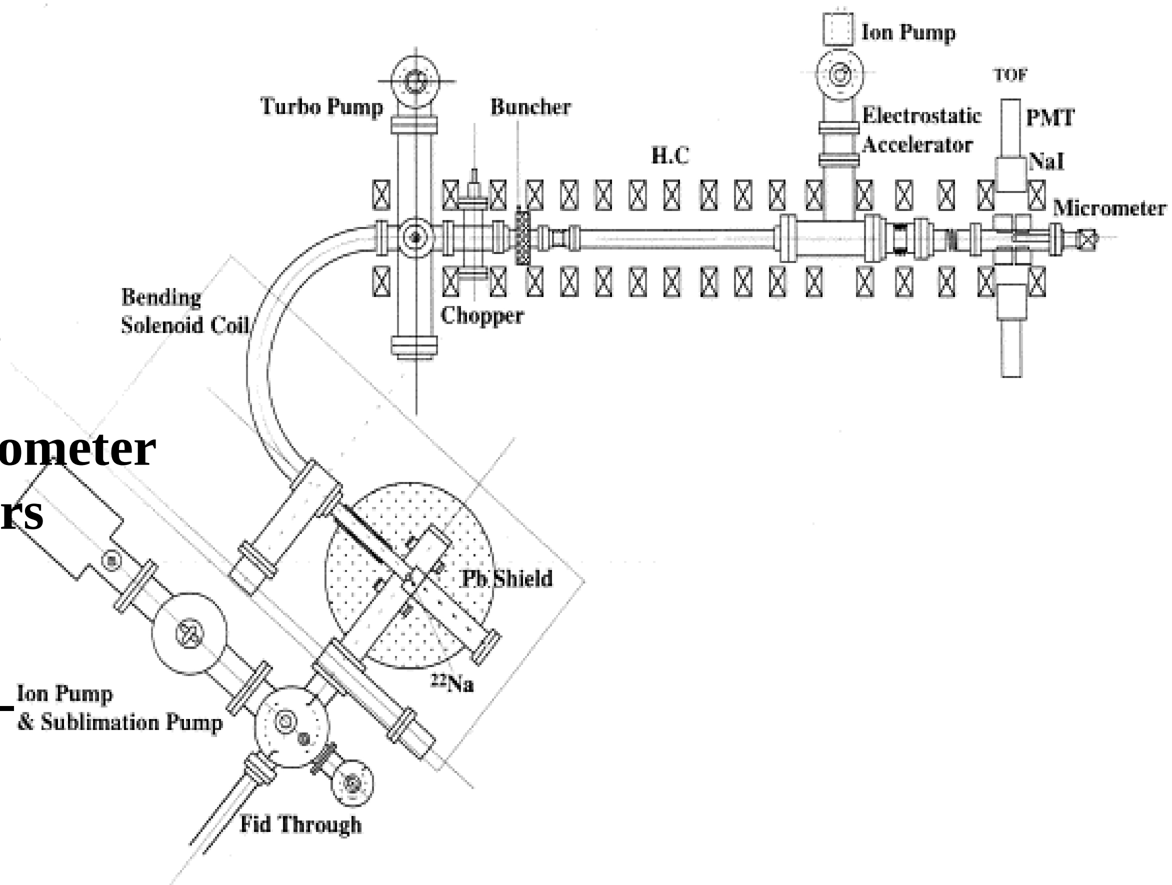
Compact Cyclotron based e^+ Source @ SHI, Japan

Curtsey: Google, Wikipedia

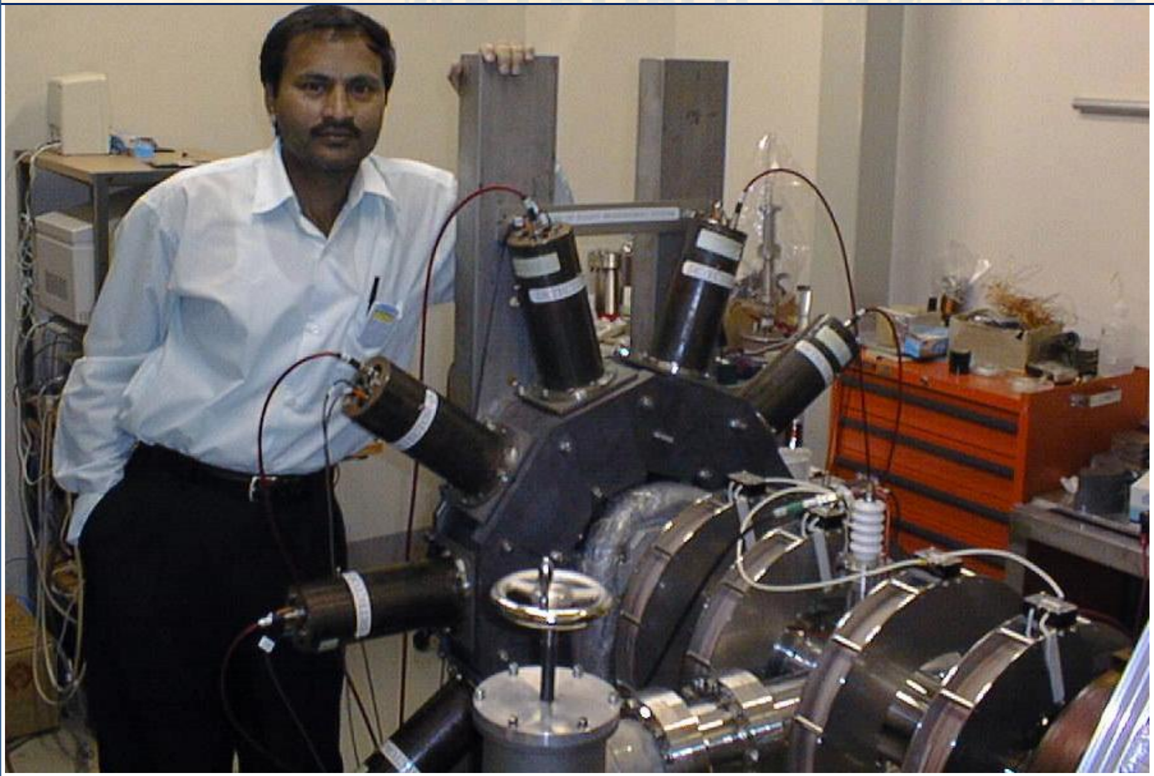
3. Radioisotope based Positron beam

- Cost effective
- Independent
- User friendly
- Example: Tokyo Metropolitan University Polarized Positron Source

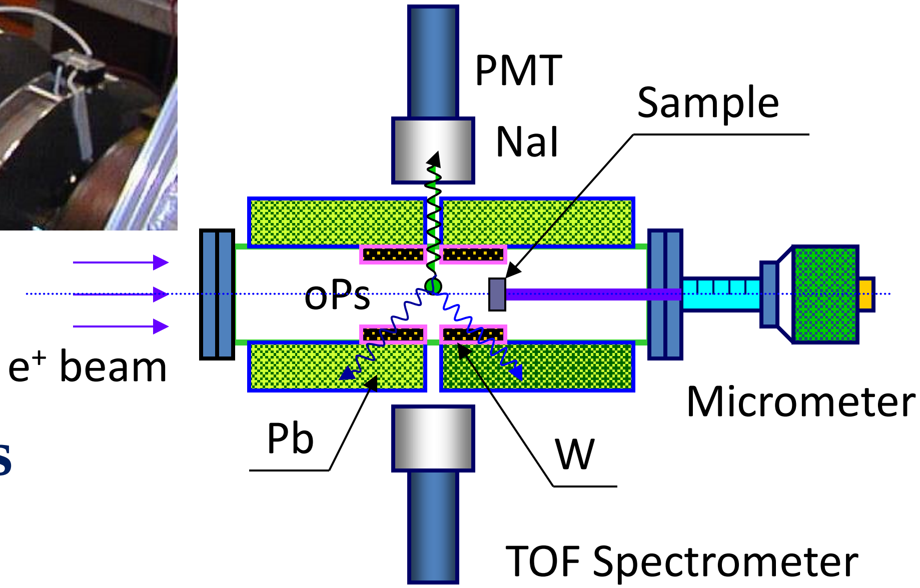
- Positron Source: ^{22}Na
- Source Strength: 150 mCi
- Half-life: 2.6 years
- UHV system: 10^{-9} torr
- Moderator: Single crystal W
- Moderator efficiency: 10^{-4}
- Positron pulsing and guiding System
- Time-of-Flight (TOF) Spectrometer
- Detectors: NaI(Tl) scintillators
- Target Chamber: Ps+Laser scattering
- Cr:LiSAF laser: Wavelength-256 nm



TIME-OF-FLIGHT (TOF) SPECTROMETER @ TOKYO METROPOLITAN UNIVERSITY, 1998



No. of Detectors: 12
NaI(Tl): from BICRON
PMT: from HAMAMATSU
Pb Thickness: 4.6 cm
W Thickness: 2.5 cm



Slit gap : 2 mm
Positron beam intensity : 10^6 e^+/s
Position resolution: 1.5 mm
Target sample: Single crystal W

Slow positron beam facilities over the world (15 -20 years back)

Names & Places	Contact persons	Positron Sources	Beam Energy	Beam I: e^+/sec	Applications
1. EPOS, Dresden	Prof. Krause-Rehberg	40 MeV e^- Linac	0.2 – 100 keV	Moderated: 10^9 and Bunched: 10^6	Defects of materials, AMOC, CDBS, PACS etc.
2. LLNL, Livermore	Dr. W. Stoeffl	Pelletron, 3 MeV	1 – 50 keV	300, 20 MHz	Defects of materials, CDBS, PAS, etc.
3. KEK-B Factory, Tsukuba	Dr. T. Kurihara	2.5 GeV e^- Linac	10 – 100 keV	10^8	2D-ACAR, TOF, Spin polarization
4. Delft Reactor Amsterdam	Prof. P. J. Schultz	Reactor based	1 eV – 40 keV	10^8	2D-ACAR, 2D-Doppler, Depth profile.
5. MRR-FRM-II, Munich	Prof. G. Kogel	Reactor based	100 eV	$10^7 – 10^9$	Positron microprobe, defect concentration
6. TOPS, Tokyo	Dr. T. Kumita, *Dr. N.N. Mondal	^{22}Na (150 mCi)	1eV – 250 keV	10^6	BEC, Laser cooling, TOF, defects, polarization
7. GU, Tokyo	Dr. I. Kanazawa	^{22}Na (3 mCi)	30 eV	10^3	Vacancy-type defects
8. Bonn University	Dr. K. Maier	^{22}Na (10 mCi)	150 eV	10^3	Surface and dislocation of materials
9. TUS, Tokyo	Dr. Y. Nagashima	^{22}Na (740 MBq)	100 eV	10^5	Ps-, moderator, defects of materials.
10. SHI, Tokyo	Dr. M. Hirose	Compact Cyclotron	10 – 150 keV	10^6	Commercial purpose, surface, interface,polarization.

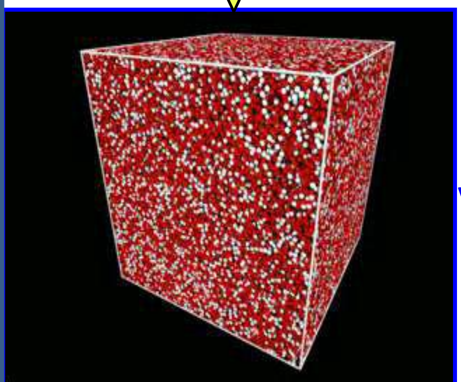
4. Applications in different branches of Science

Defect studies of materials

Ref. : Prof. R. Krause-Rehberg

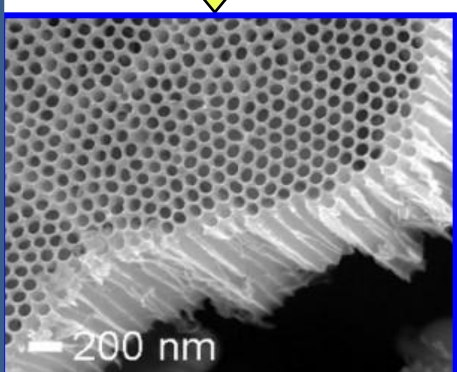
Alkali borosilicate glass

T: 530- 710 °C

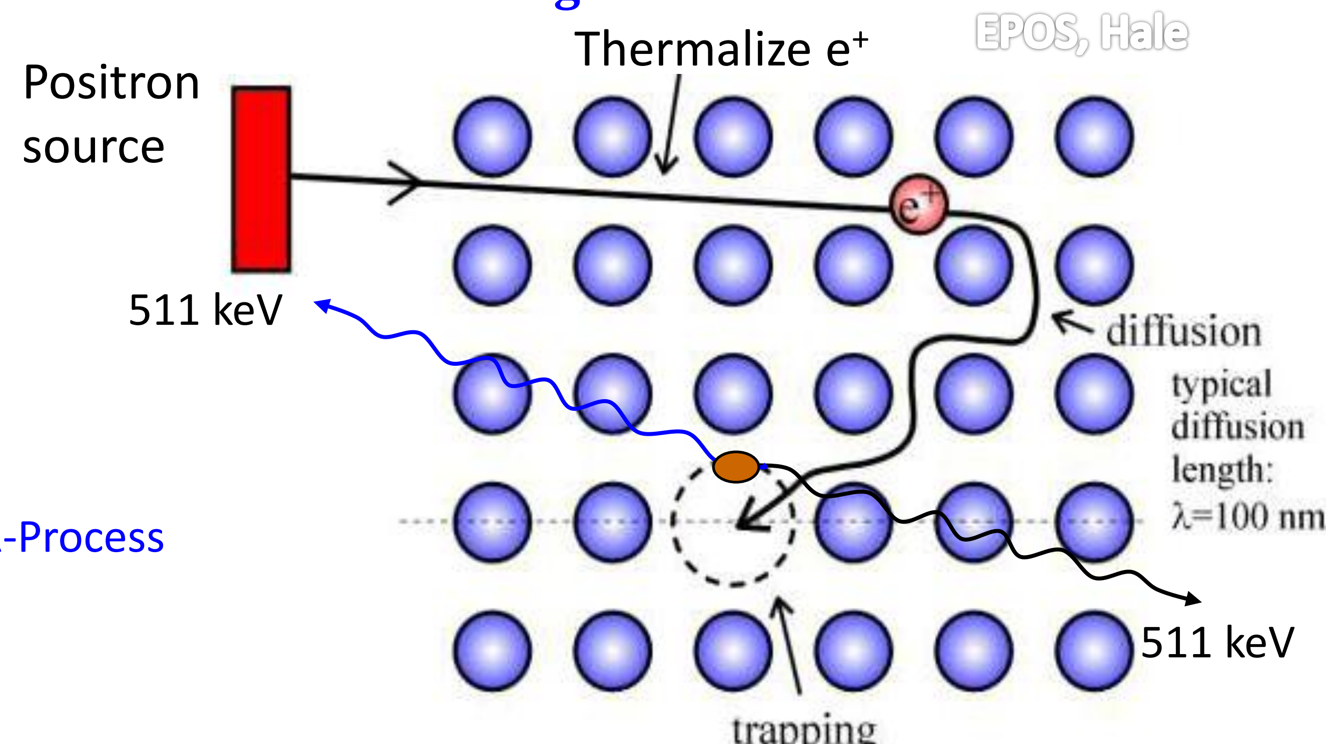


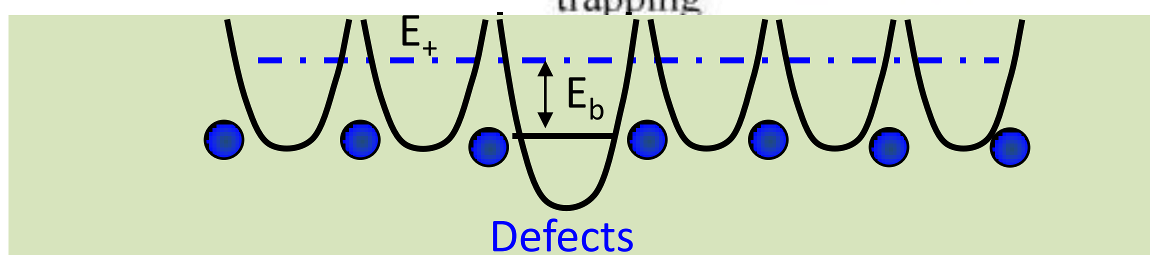
VYCOR-Process

Extraction: HCl/NaOH



CPG (controlled pore glass)





CPG: It will be a good candidate for PsBEC

5. Fundamental Research with Positron beams

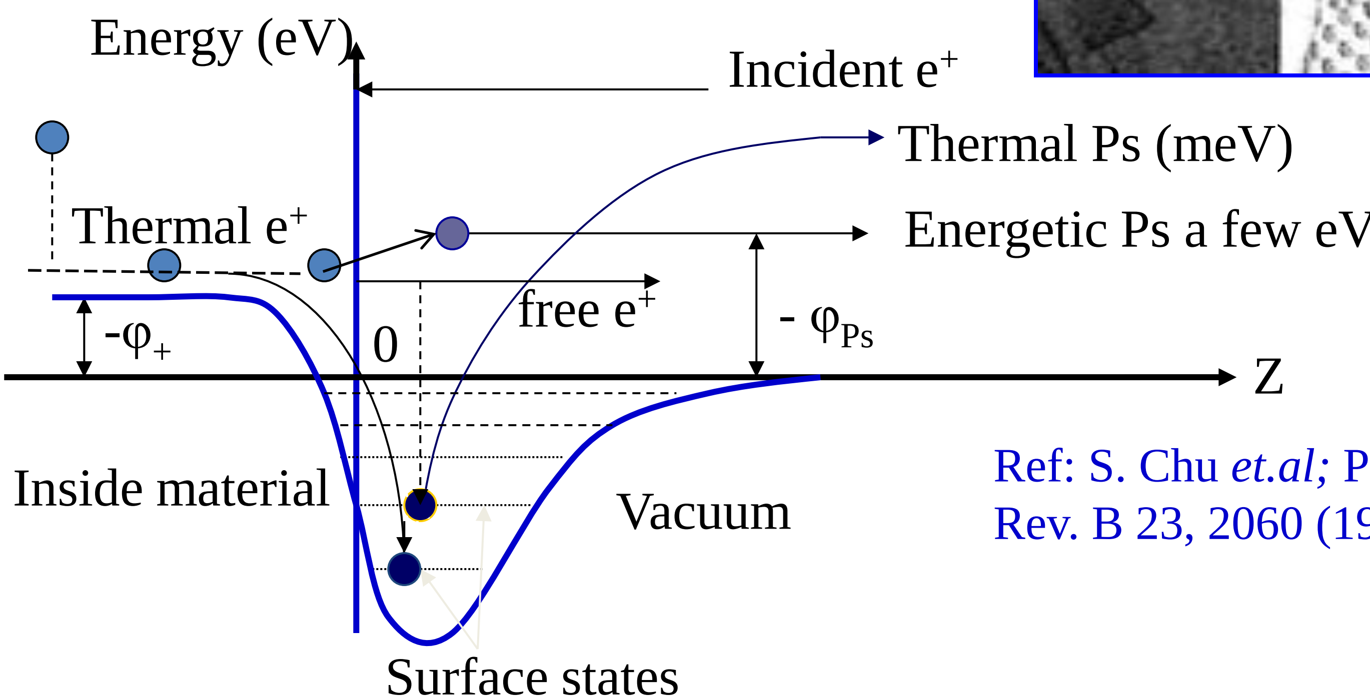
- The Ps work function: $\varphi_{Ps} = -\mu_{Ps} + E_B - ½ R_\infty$,

where $½ R_\infty = 6.8$ eV. Ps formation potential:

$$\varepsilon_{Ps} = \varphi_- + \varphi_+ - ½ R_\infty ,$$

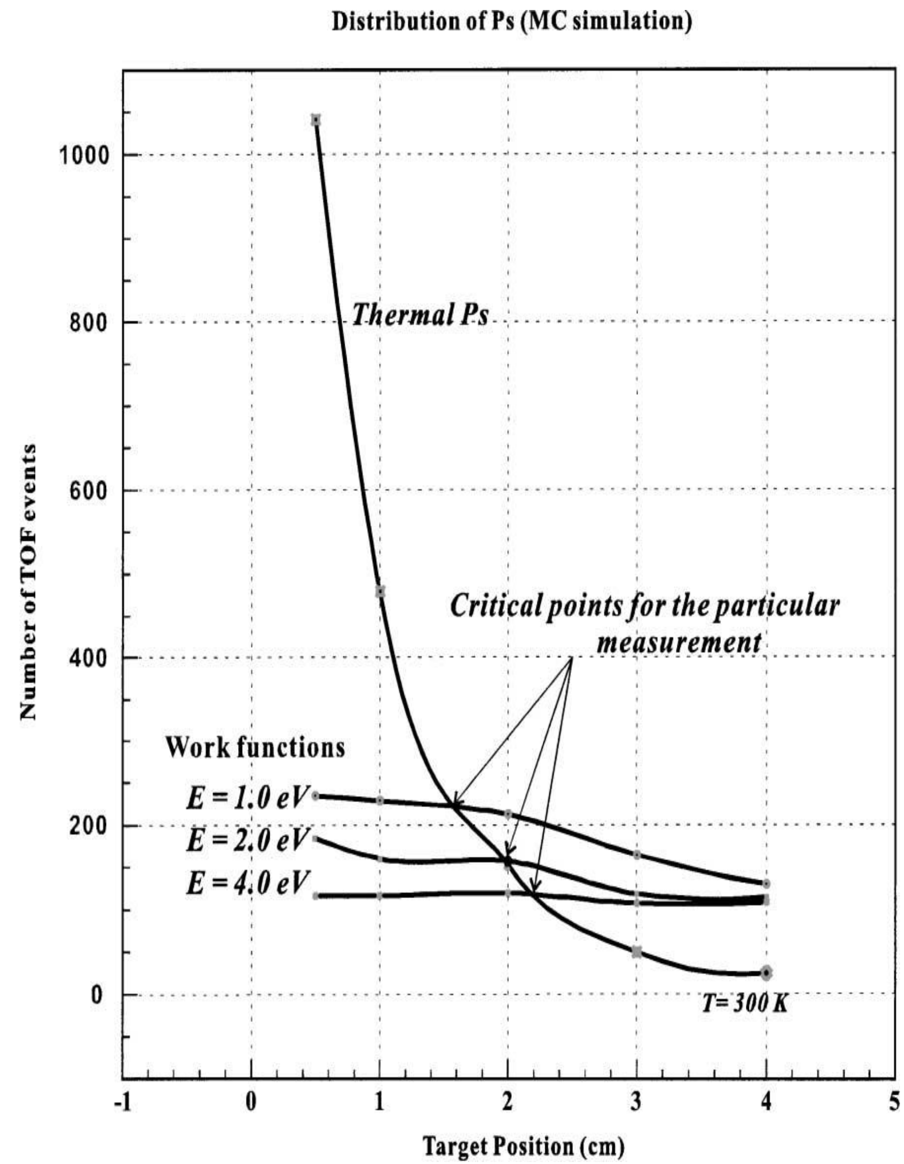
$$\text{Where, } -\mu_{Ps} = \varphi_- + \varphi_+$$

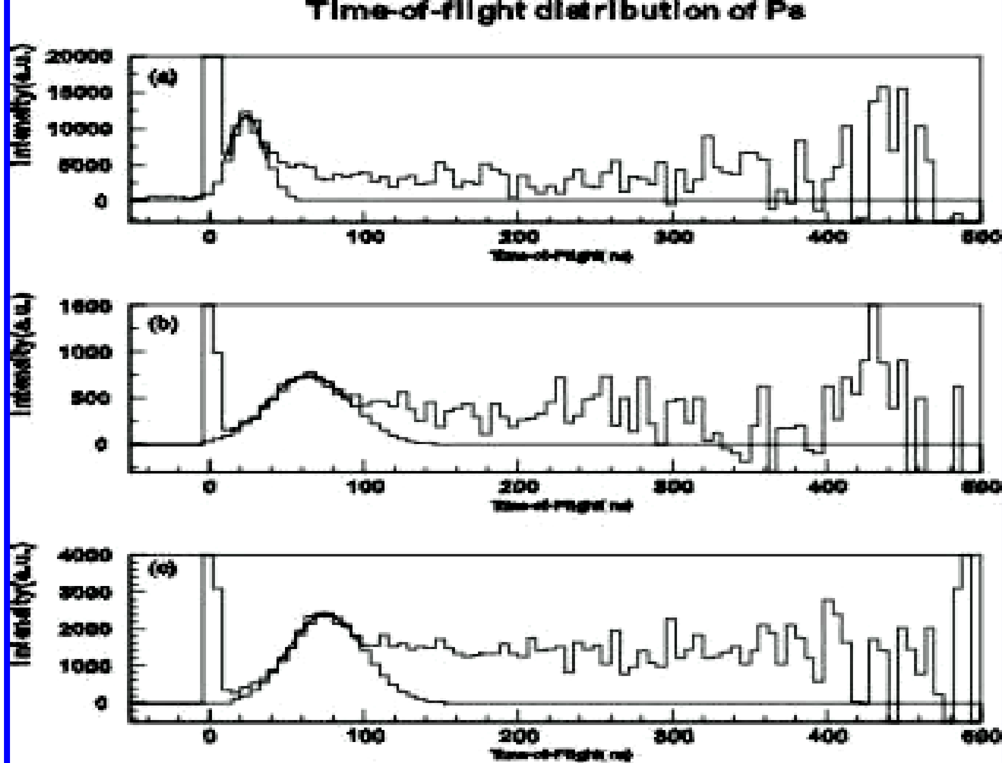
- E_B: the binding energy of Ps
- Ps chemical potential: μ_{Ps}

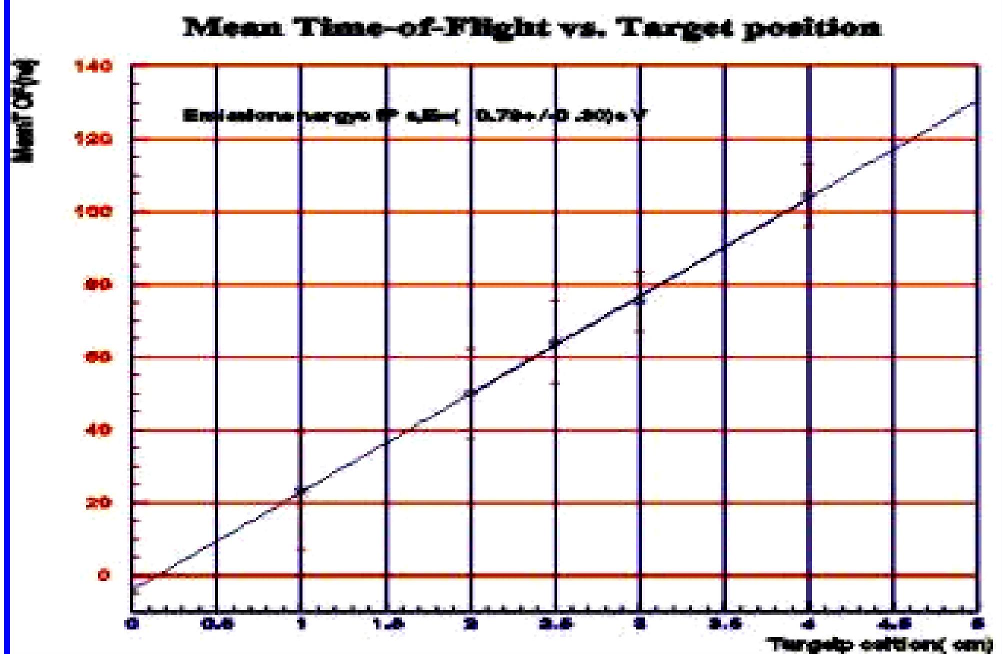


Ref: S. Chu *et.al;* Phys. Rev. B 23, 2060 (1981)

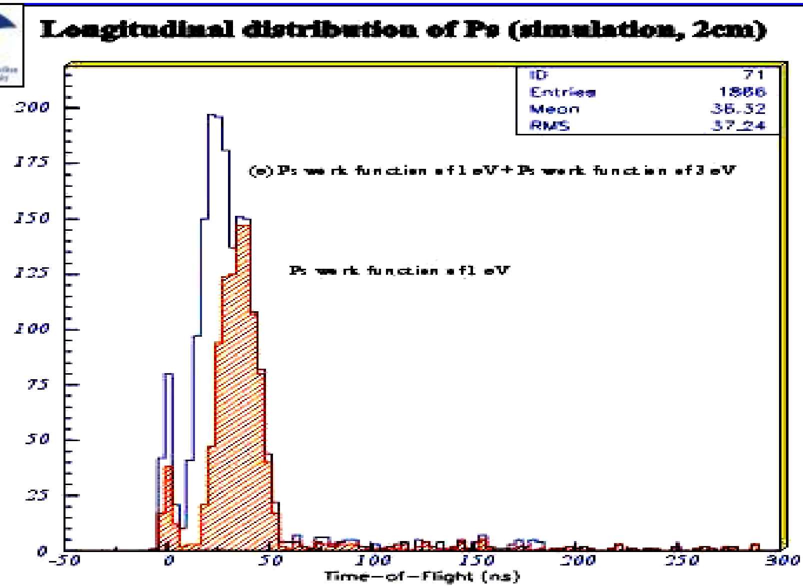
Measurement of Thermal and Work function Positronium @ TMU [App. Surf. Sci.]

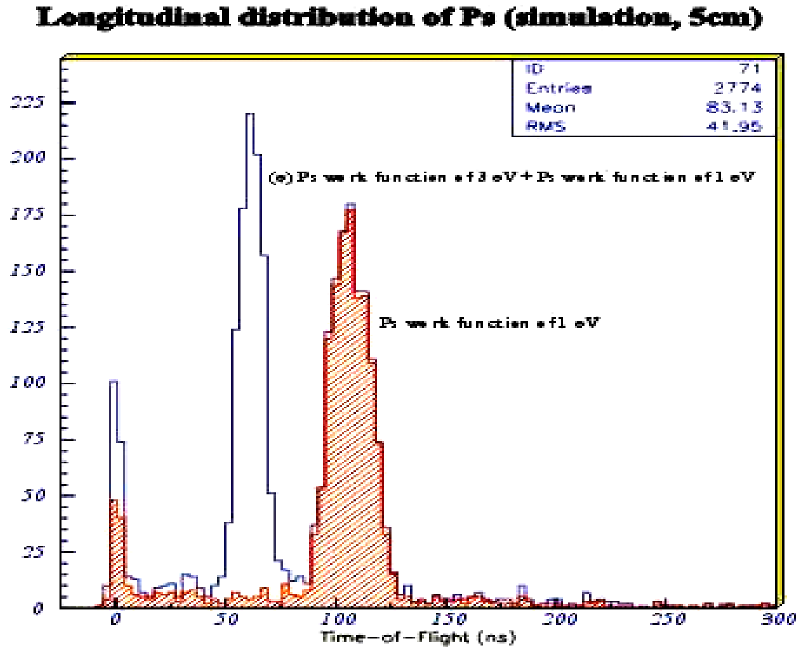


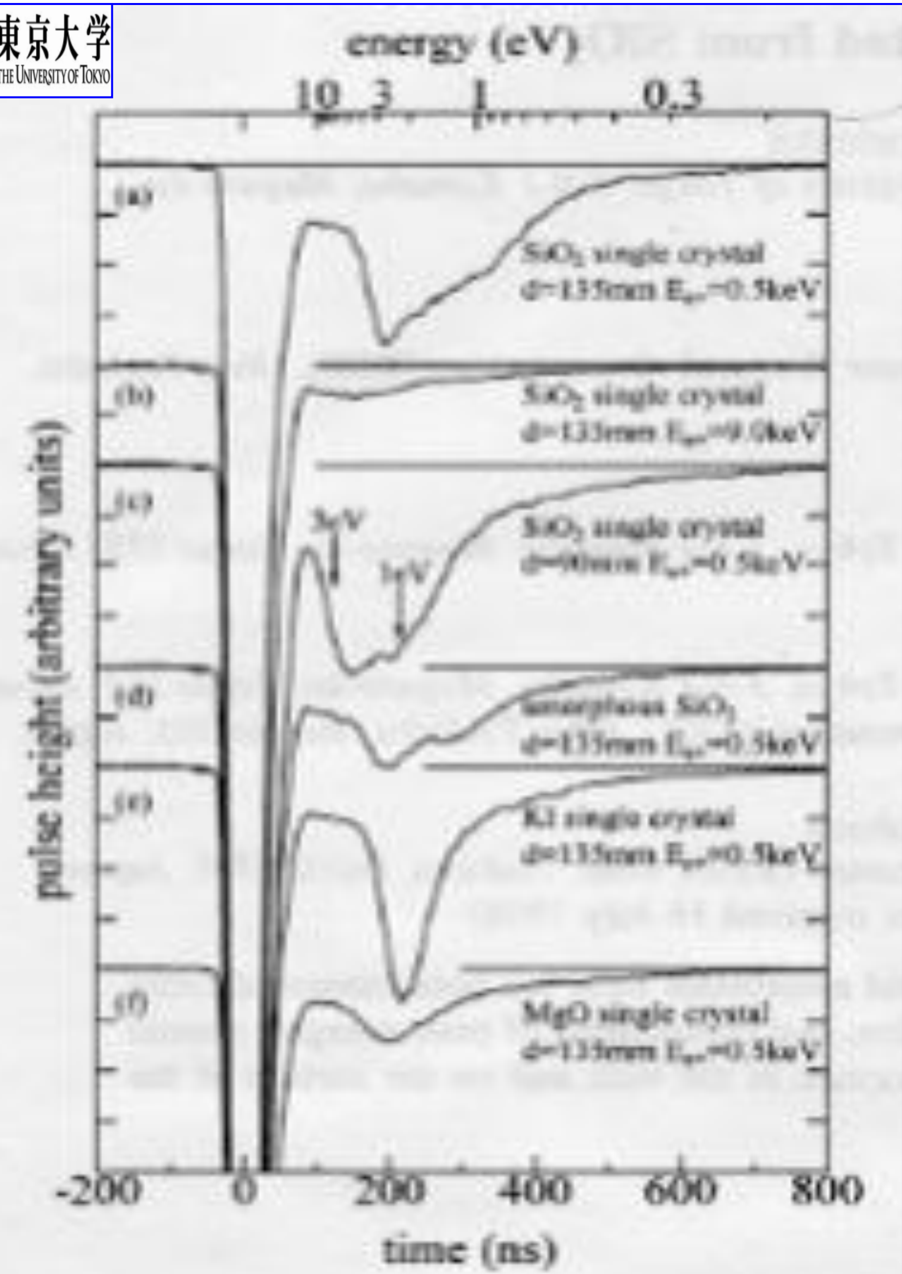




MC simulation for 1 eV and 3 eV Ps and their measurements



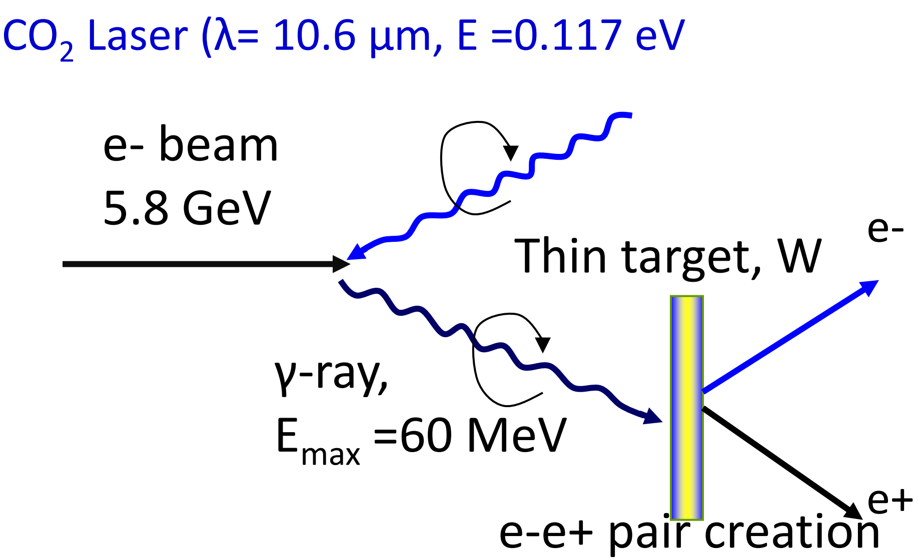


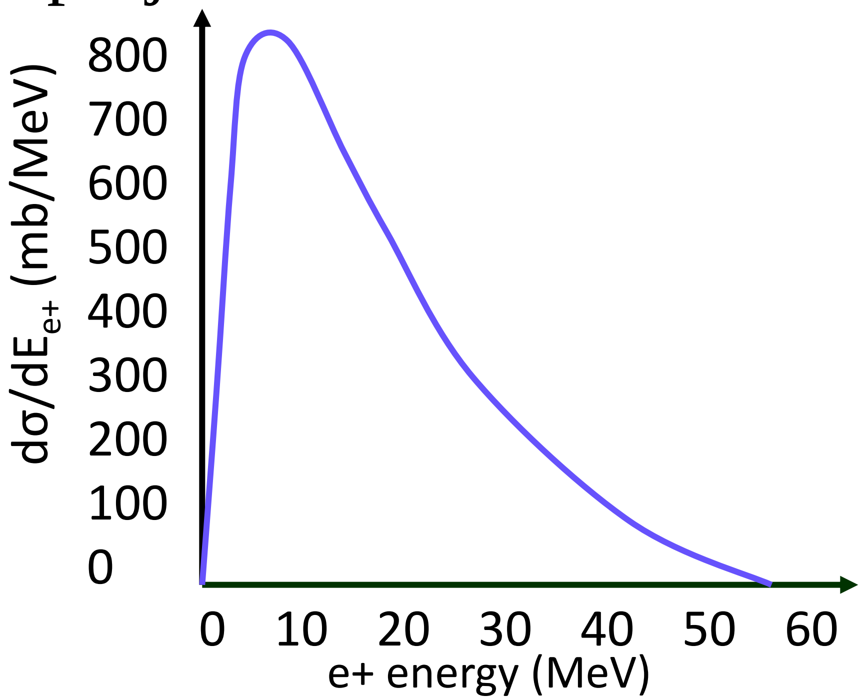


TOF -MCS, N. N. Mondal & TOF Expt., Y. Nagashima (*Physical Review B*).

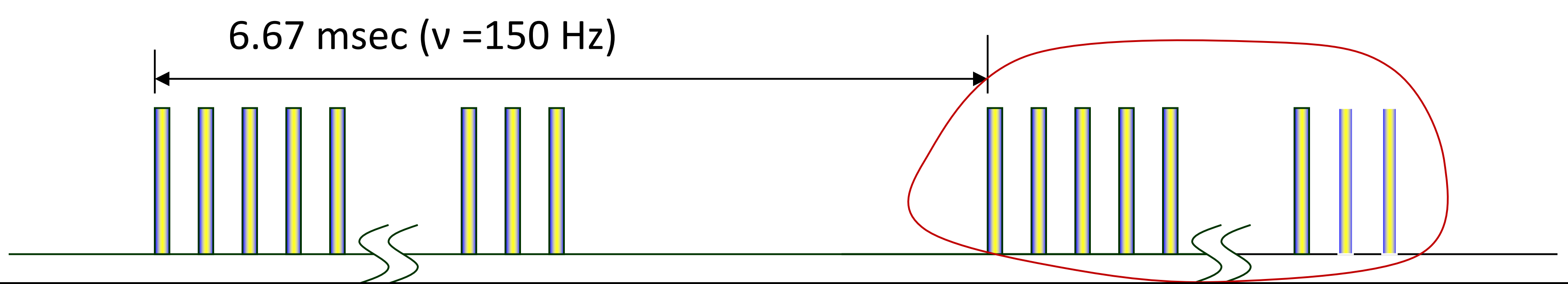
6. Production of high intense positron beam

- High intensity polarized positron source
- (a) Polarized e^{+} source for JLC project





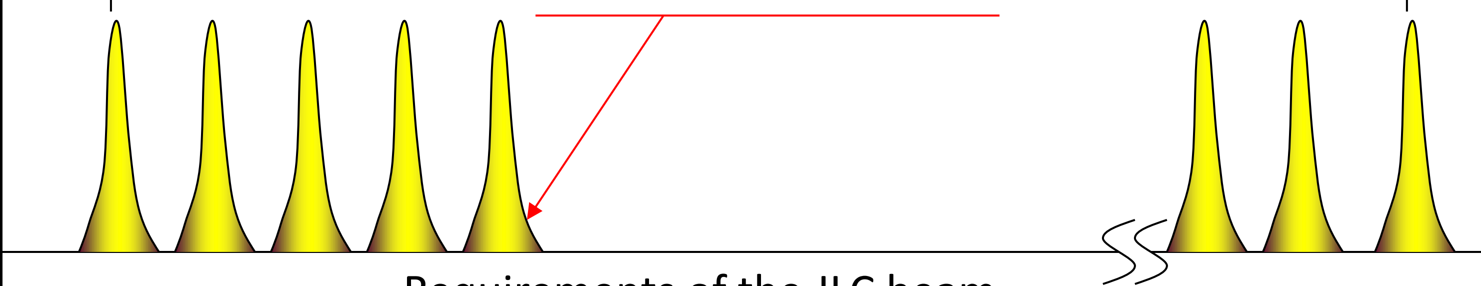
Principle of polarized e+ source:



Polarized e^+ source for JLC project

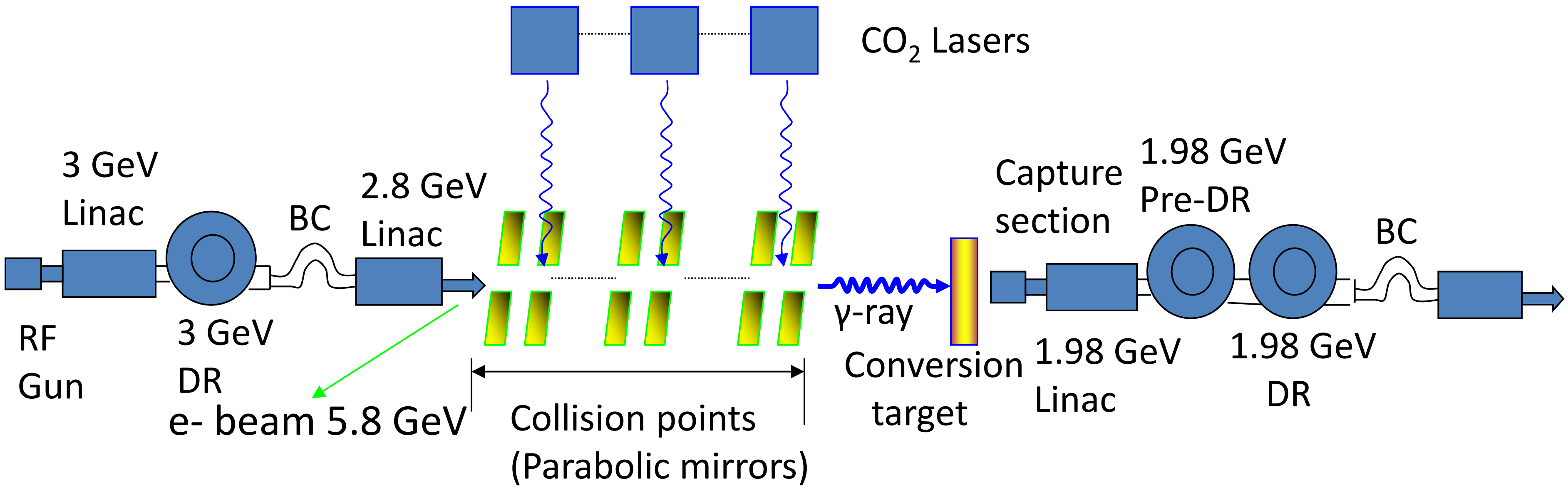
95 bunches = a train

$1.1 \times 10^{11}\ e^+$/bunch



Requirements of the JLC beam

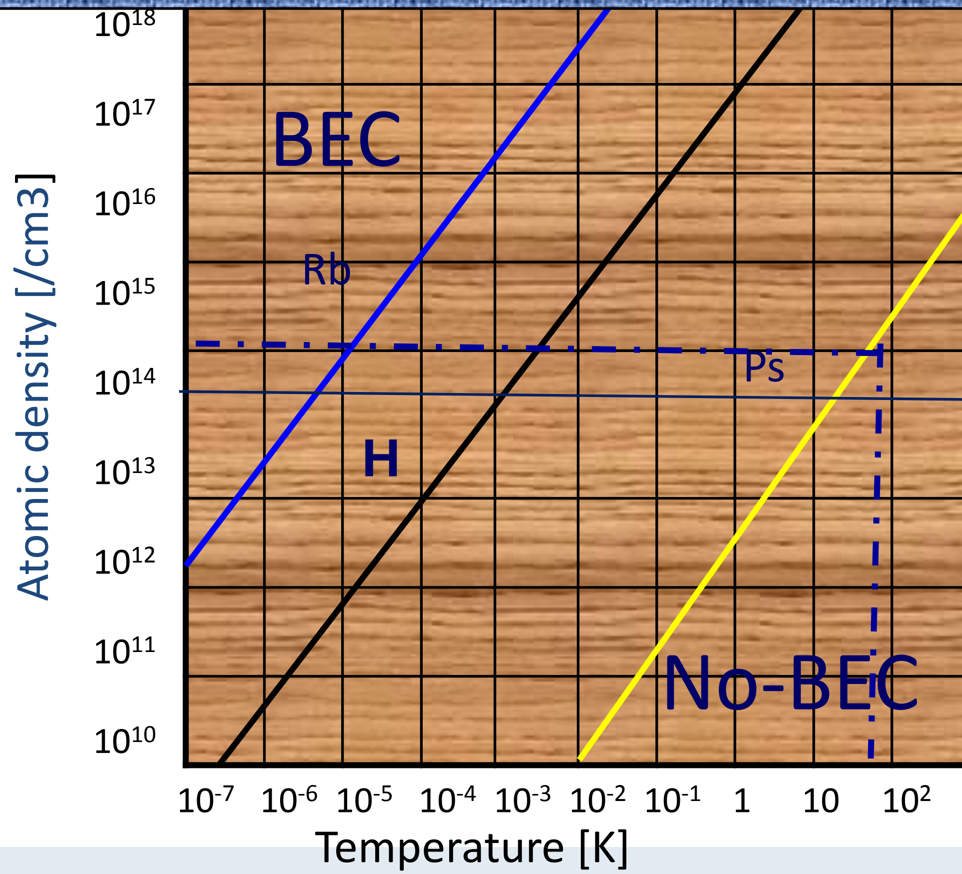
Configuration of the polarized e+ Source for the JLC project

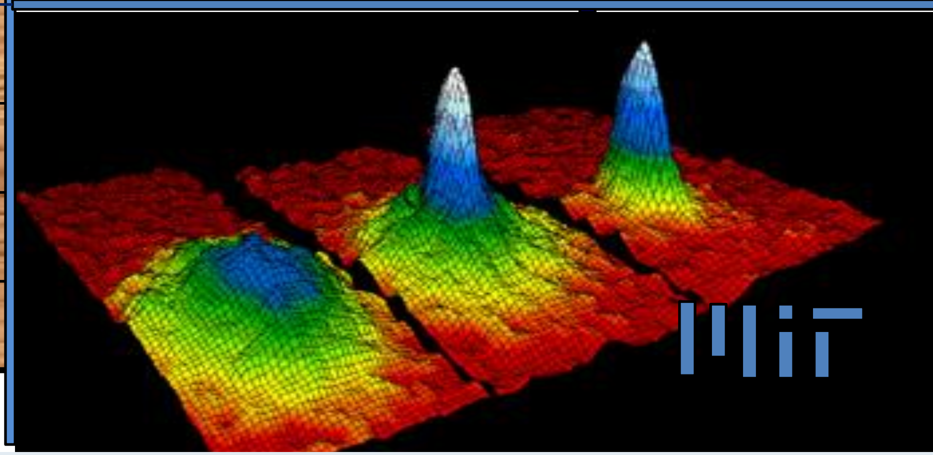


Expected e^+ intensity: 10^{13} /train; best for the PsBEC

Tokyo Metropolitan University

7. Achievement of PsBEC



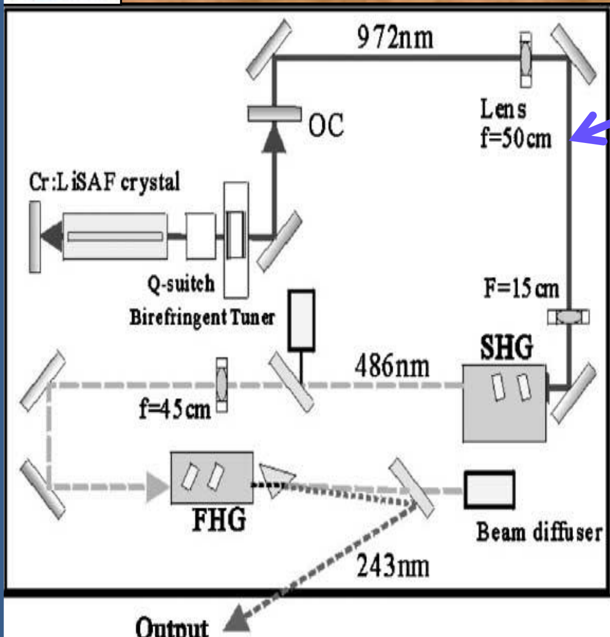


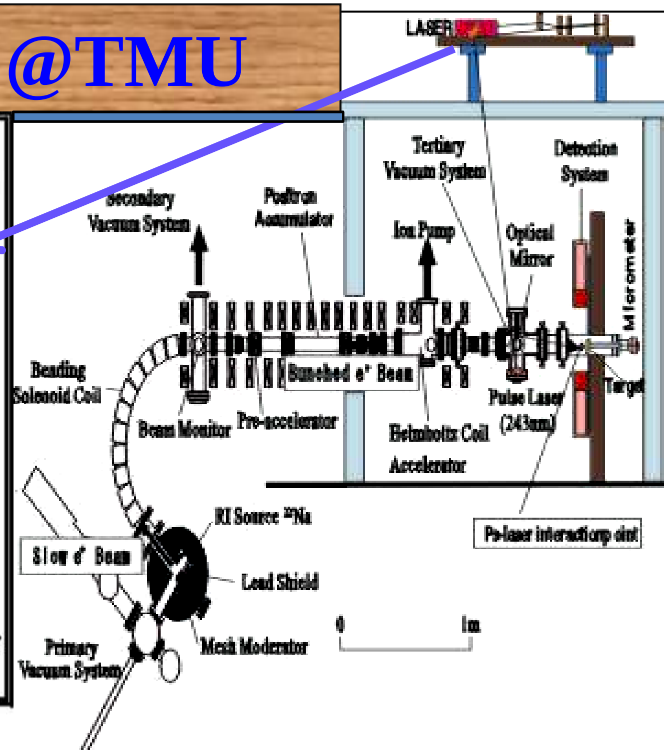
De Broglie wave length, $\lambda_D = \dfrac{h}{\sqrt{2\pi mKT}}$

Phase space density, $\rho = n\lambda_D^3$**, Condition for occurring BEC,** $\rho \gg 2.617$

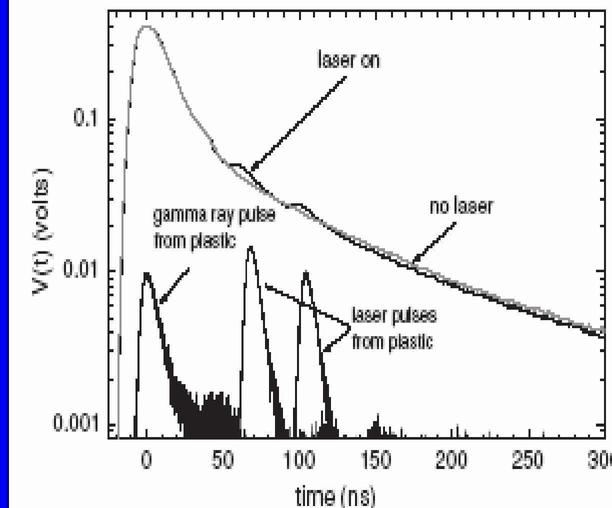
7. Detection of PsBEC

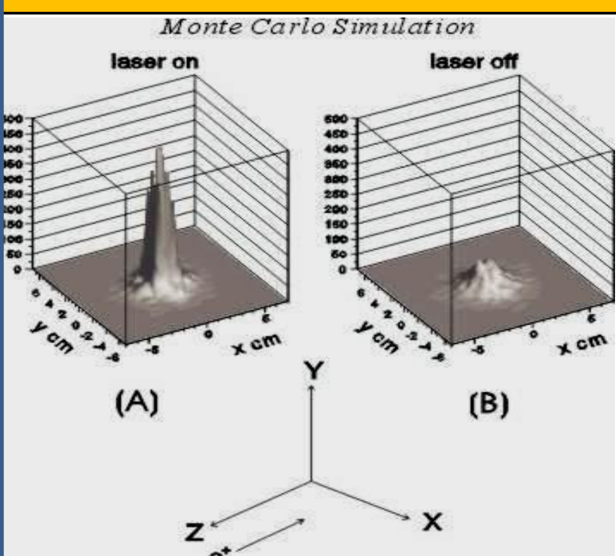
Laser Cooling @TMU

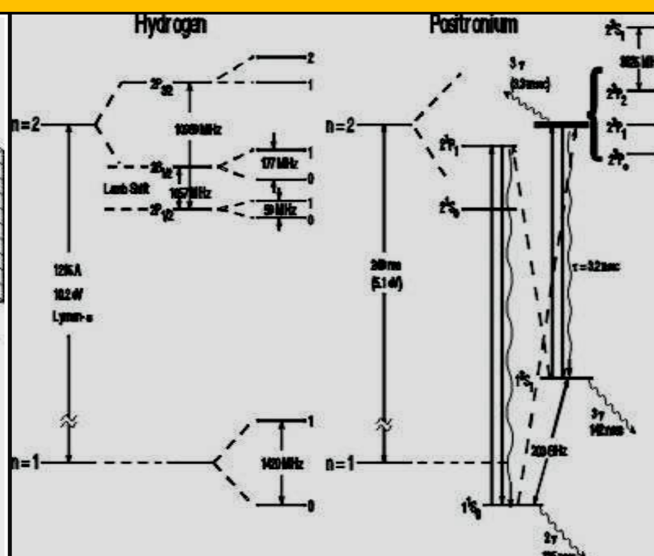


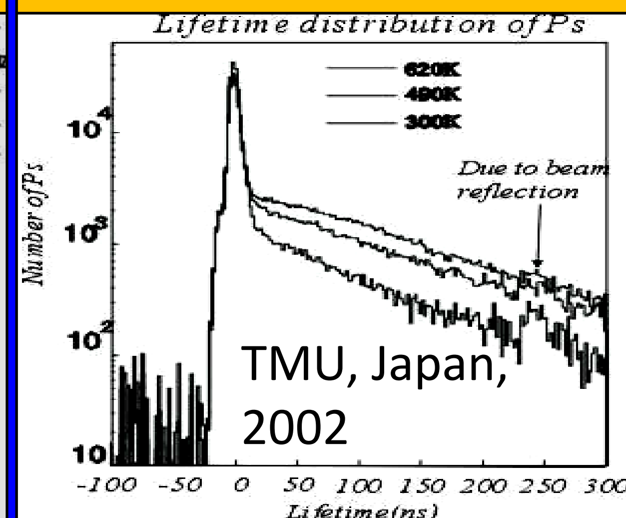


Prof. A.P. Mills Riverside, USA, in 2010

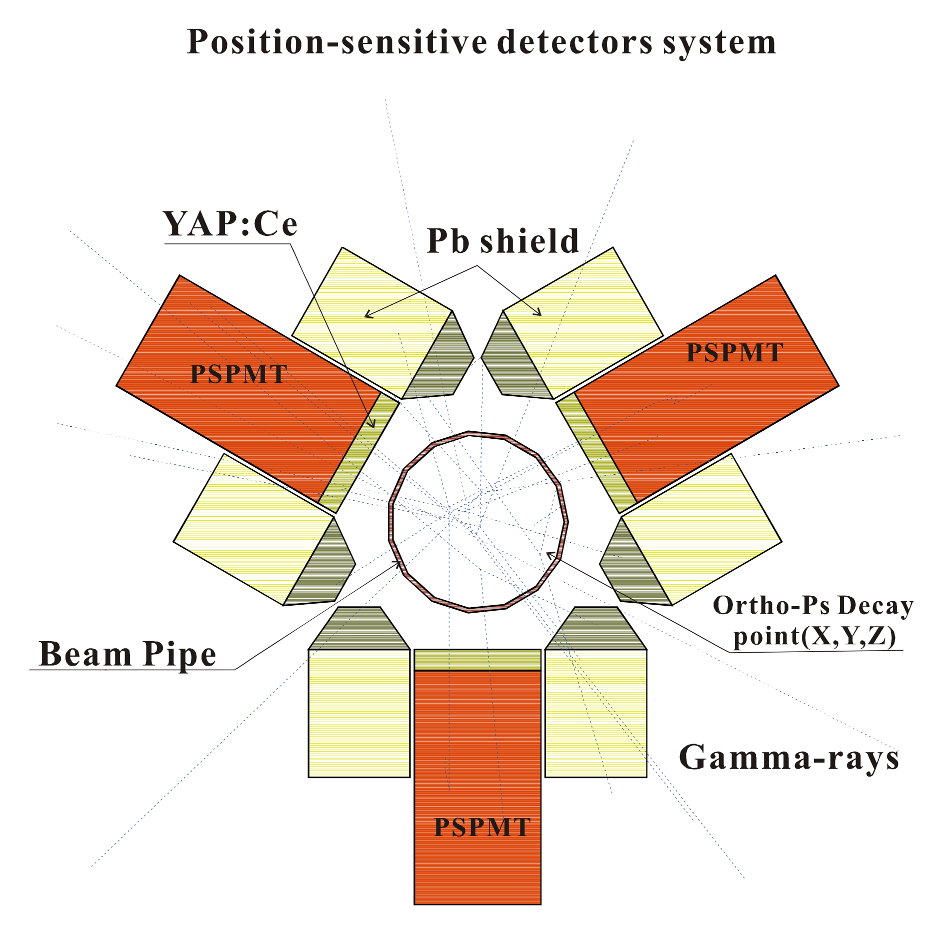


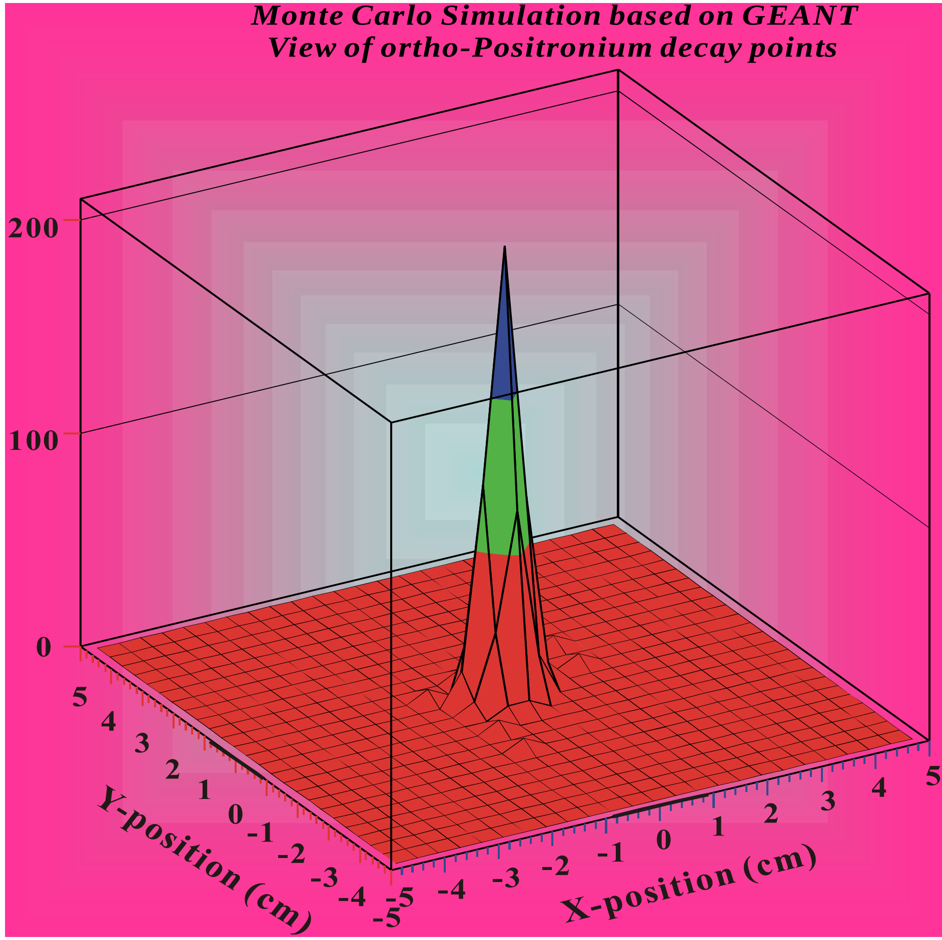






Monte Carlo Simulation based on GEANT





Position-sensitive Gamma-ray detectors system is used to visualize The laser cooled ortho-Ps. Spatial resolution is 2 mm. It is an ideal system for imaging PsBEC

N.N. Mondal, Nucl. Inst. and Meth. in Phys. Res. A 495 161-169 (2002).

Acknowledgement

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Thanks for your attention