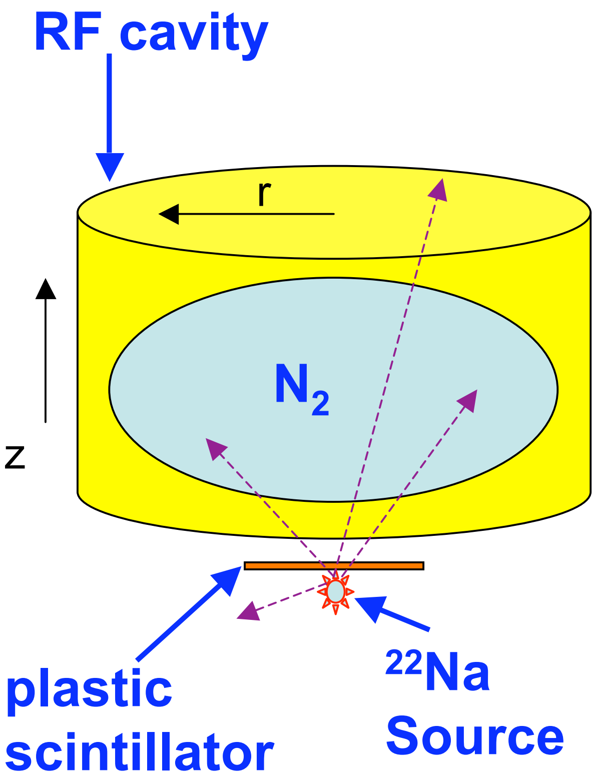
Positronium assembly system for the precise measurement of the Positronium hyper-fine splitting

東大理, 東大素セ[A], 東大院総合文化[B] , 高エ研[C], 福井大遠赤セ[D]

Mark M. Hashimoto , 秋元銀河, 石田明, 田川智博,
末原大幹[A], 難波俊雄[A], 浅井祥仁, 小林富雄[A], 斎藤晴雄[B],
吉田光宏[C], 小川勇[D], 小林真一郎[D], 出原敏孝[D]

Japan Physical Society Autumn Meeting 2008
Yamagata University 2008-09-21

Motivation for this work



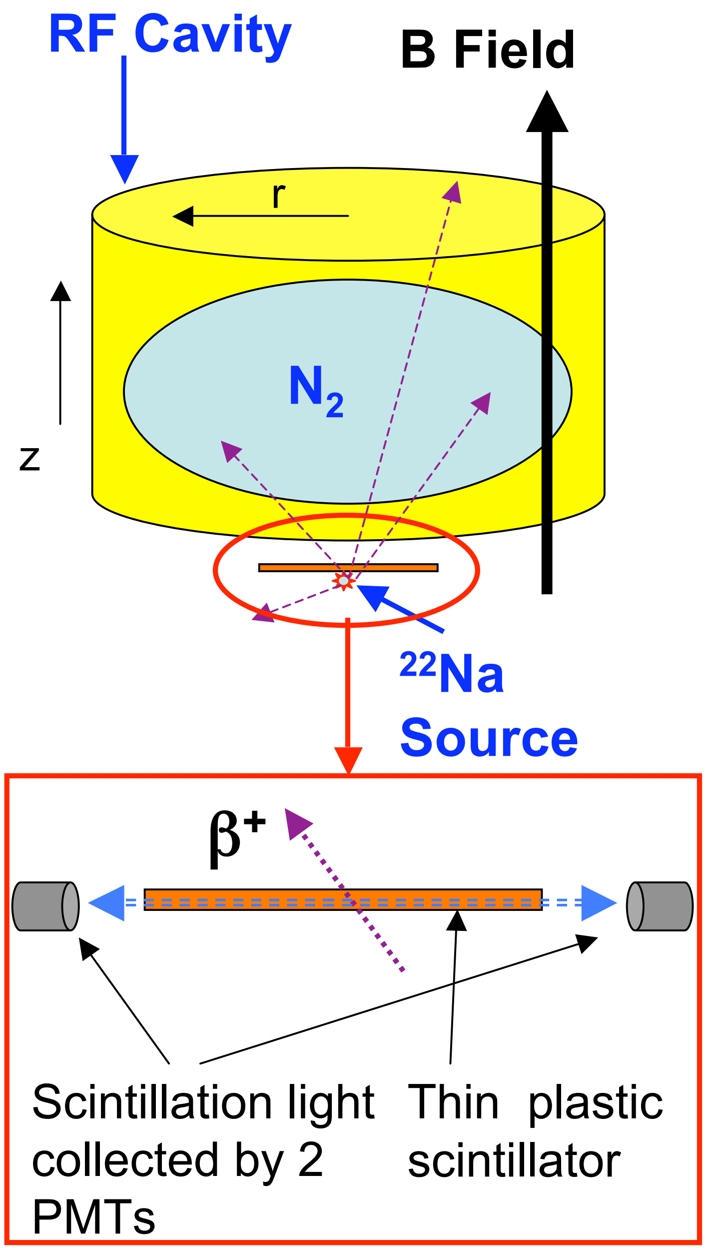
In order to maximise the rate of production of measurable positronium (Ps) within the RF cavity we must optimise the design of the cavity and the positron time-tagging system:

- The design of the plastic scintillator (PS) tagging system which time-tags the incoming positrons and its instalment in the cavity.
- Cavity dimensions: r & z.
- N_2 density

Outline

- Discussion of the parameters which affect the Ps production rate in the RF cavity and of an MC simulation created to decide the cavity/tagging system design.
- Description of a practical plastic scintillator tagging system being implemented.
- Results of an experiment to measure the Ps creation efficiency in N_2 gas using this plastic scintillator tagging system

Factors affecting Ps Production Rate

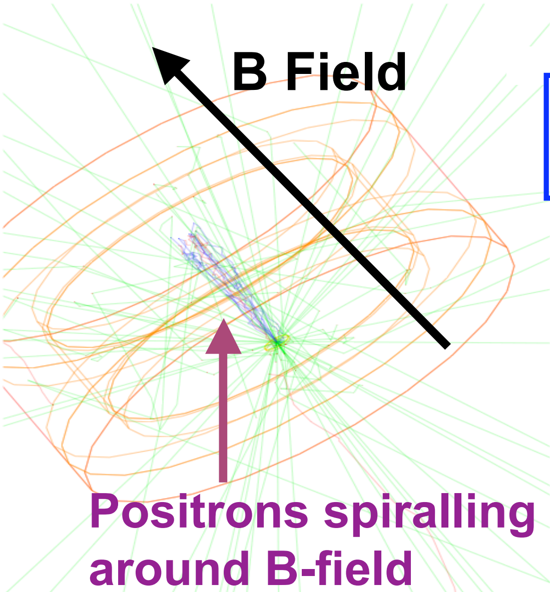


To increase measurable Ps production we want to maximise the population of **tagged AND stopped** positrons in the RF cavity.

1. The positrons entering the chamber must be time-tagged by thin plastic scintillator. Energy loss in the plastic will affect tagged Ps production rate:
   - PS too thin⇒small light yield⇒no tag
   - PS too thick ⇒ positrons will stop in the PS and thus won't form Positronium
2. N_2 gas pressure
   - High pressure ⇒high energy loss⇒high stopping efficiency BUT
   - Applicable pressure within cavity is limited by the thin 2mm Cu gamma window of the cavity (~2atm). High pressure will also increase o-Ps pick-off.
3. Cavity dimensions are limited by our need for good separation of the 2856MHz TM_{110} resonance: φ=12.8cm fixed, z≈10cm required.
4. Once the positrons have stopped, the ratio which actually form Ps.

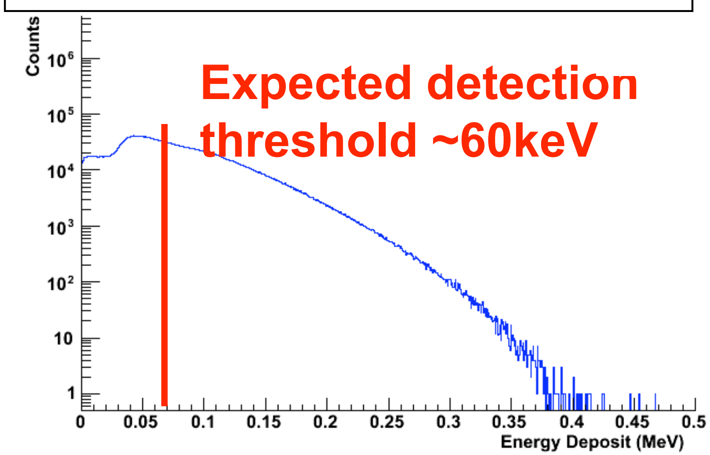
Positron Tagging and Stopping Efficiency Simulation

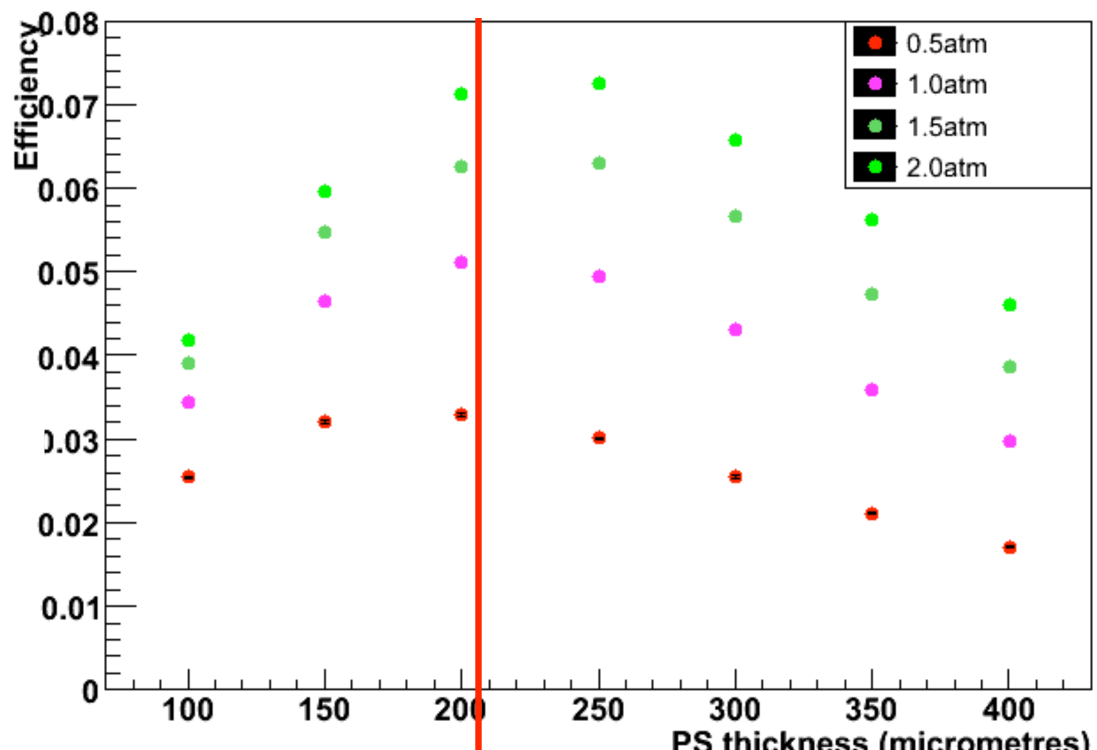
MC simulation run in order to optimise factors affecting Ps production



$$Efficiency = \frac{(\text{Energy Deposit in PS} > 60\text{keV})\ \&\ (\text{Stop in Cavity})}{\text{Positrons Emitted}}$$

Energy deposited in plastic scintillator

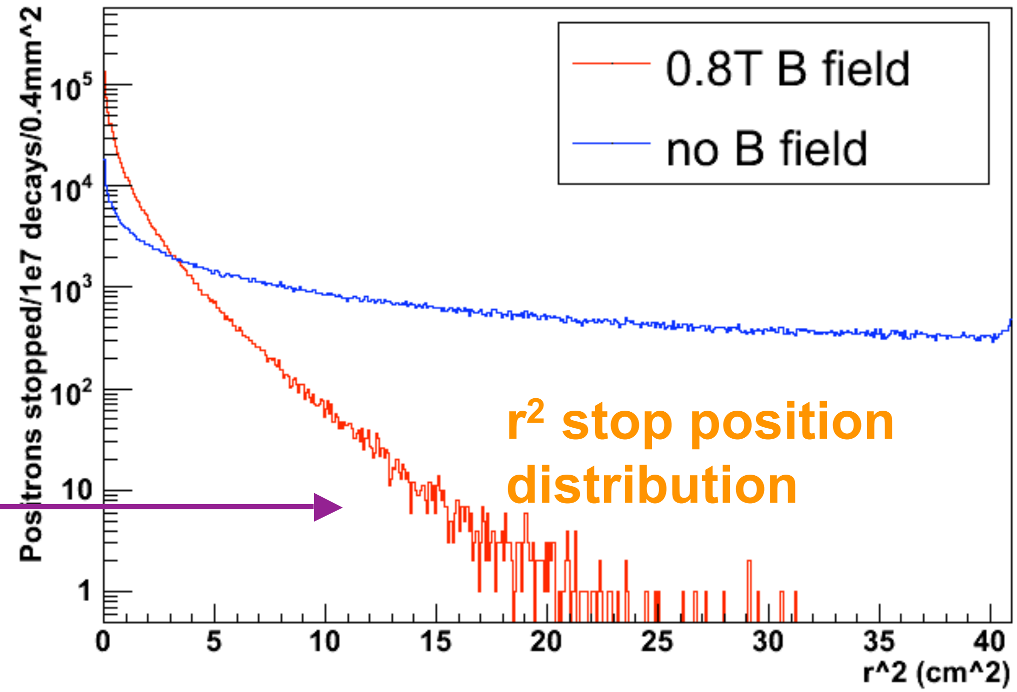




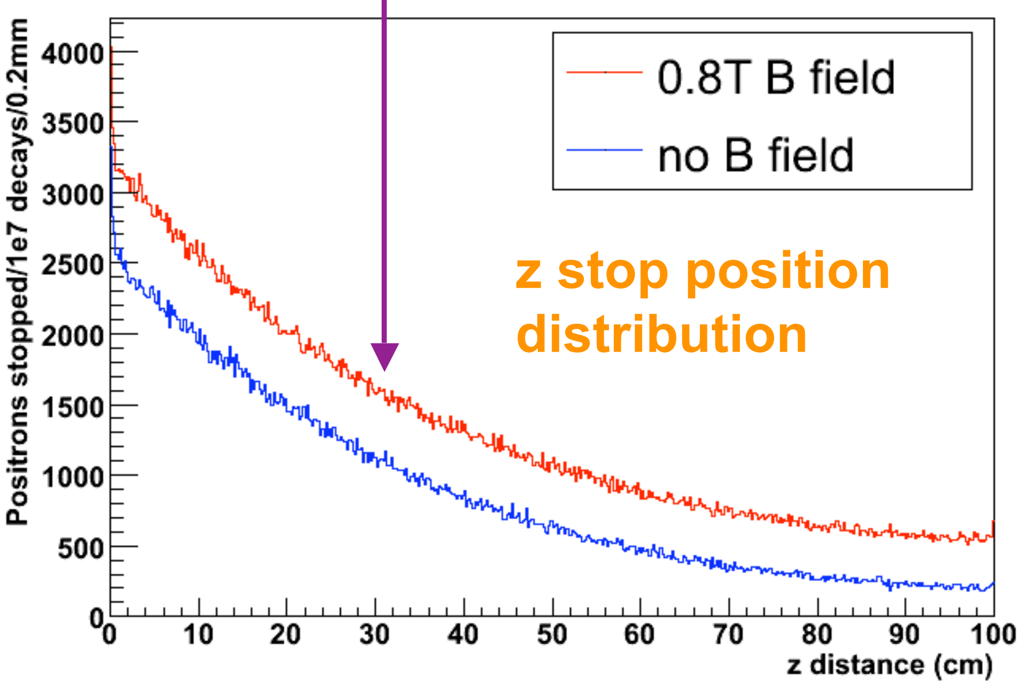
Optimum PS thickness is ≈ 200μm

Positronium Confinement

MC simulation for 200μm thick plastic scintillator and 2.0atm N_2 gas.



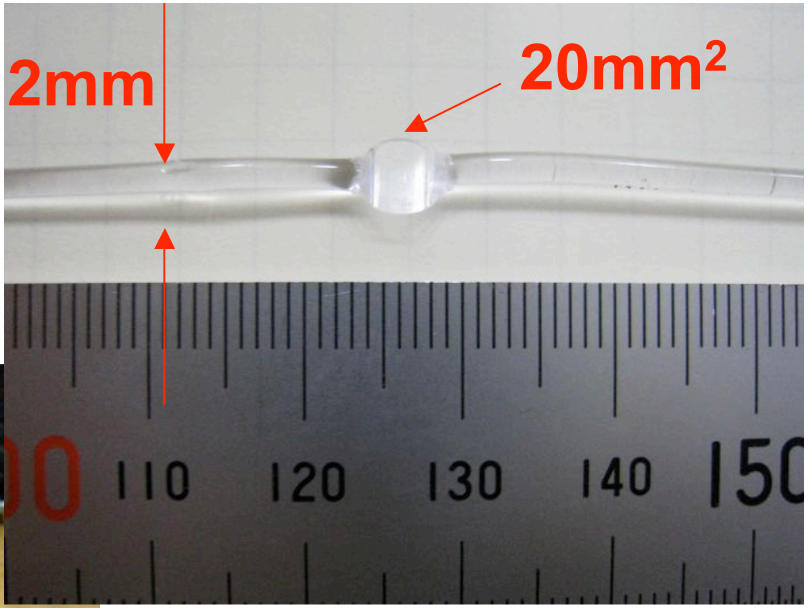
Positrons' spiralling around B-field help to confine Ps radially, and also to increase positron energy loss and thus overall stopping efficiency

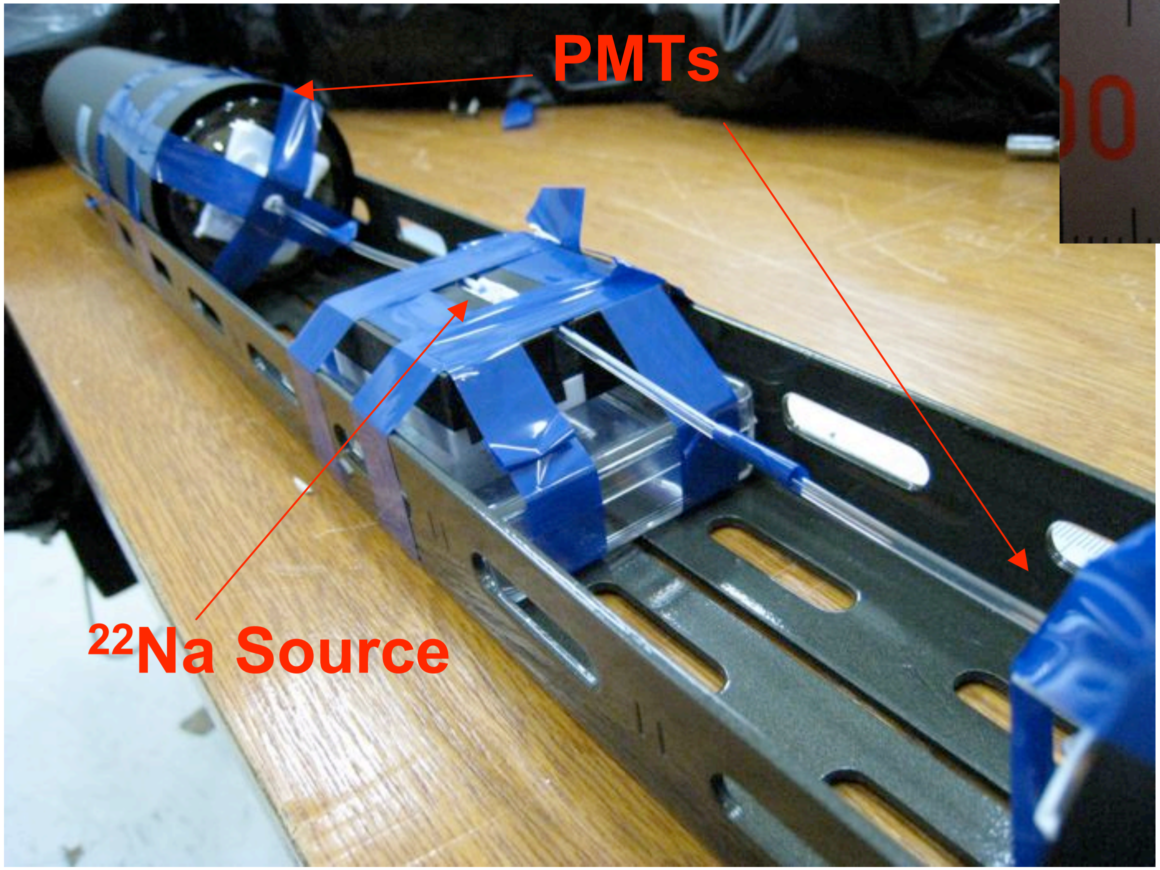


The uniformity of the magnetic field at the position of the formed Ps is an important factor for our precision measurement of the Ps HFS. With a 0.8T B field applied **96%** of the tagged & stopped positrons are confined to within **r<2cm** in the cavity (cf. **40%** for the case of no field).

3.6% of tagged positrons hit the top of the cavity

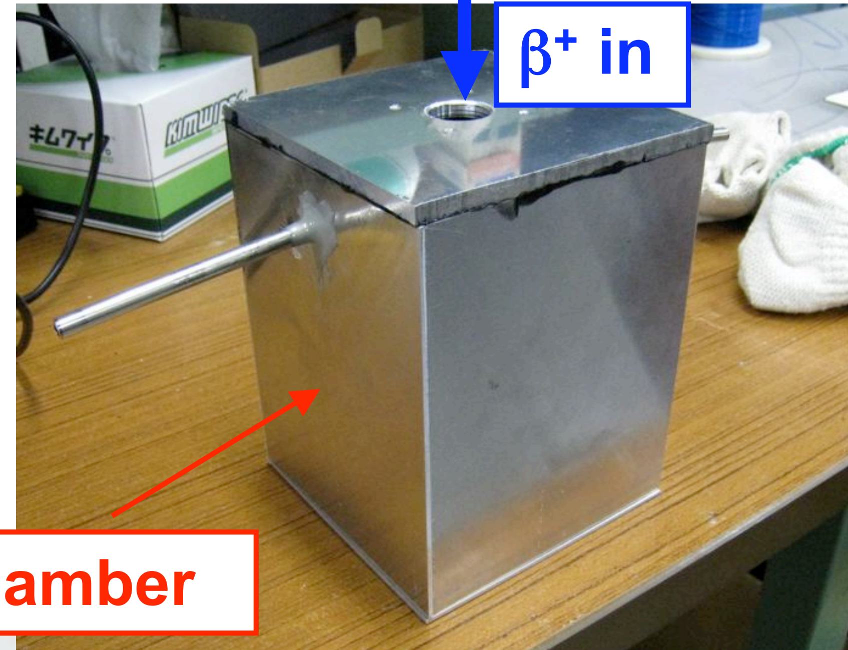
Plastic Scintillator Fibre used to tag Ps





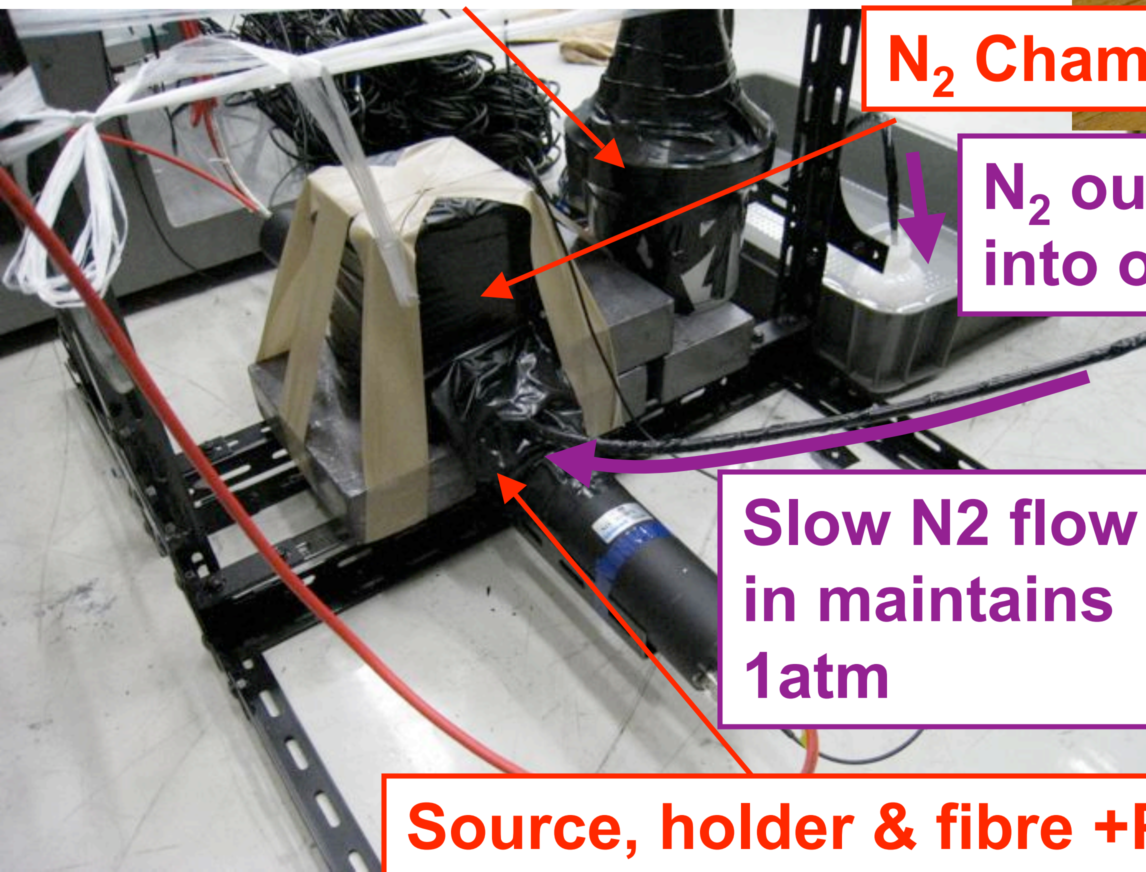
POSITRON TAGGED BY COINCIDENCE TRIGGER

Ps creation efficiency test setup



β⁺ in

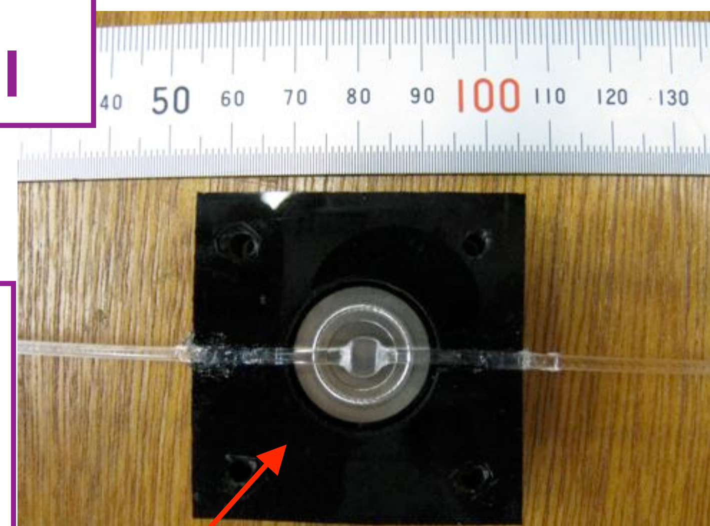
N$_2$ Chamber



φ125x125 NaI detects Ps decay γ (TDC stop)

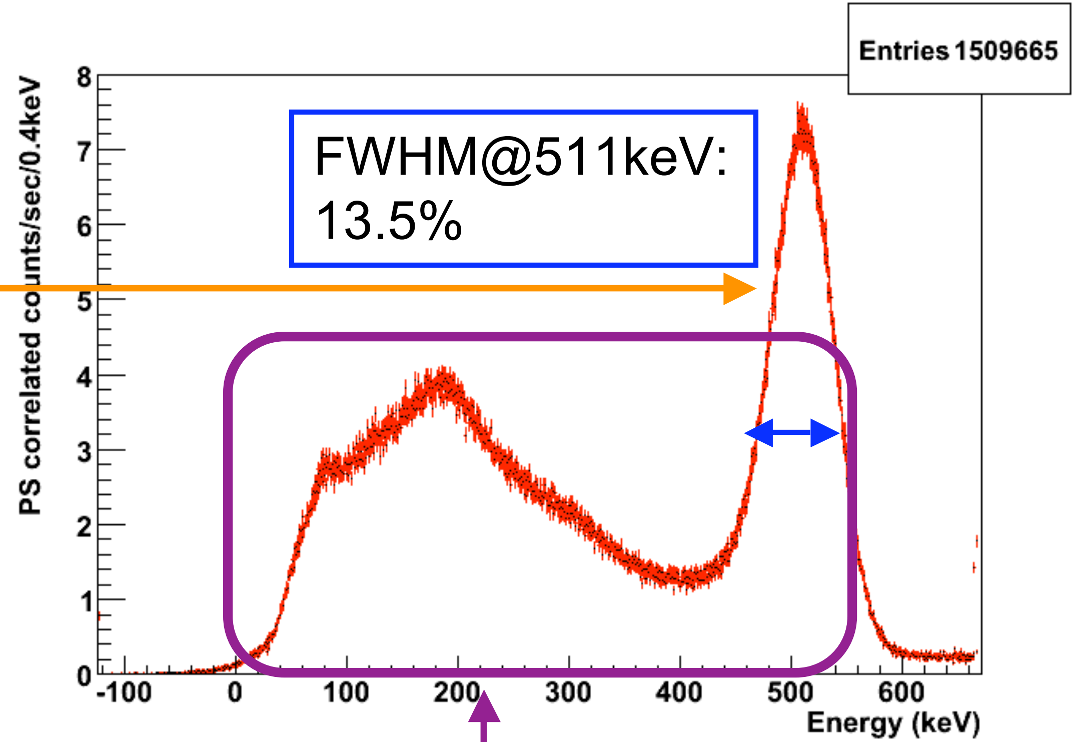
N$_2$ out into oil

Slow N2 flow in maintains 1atm



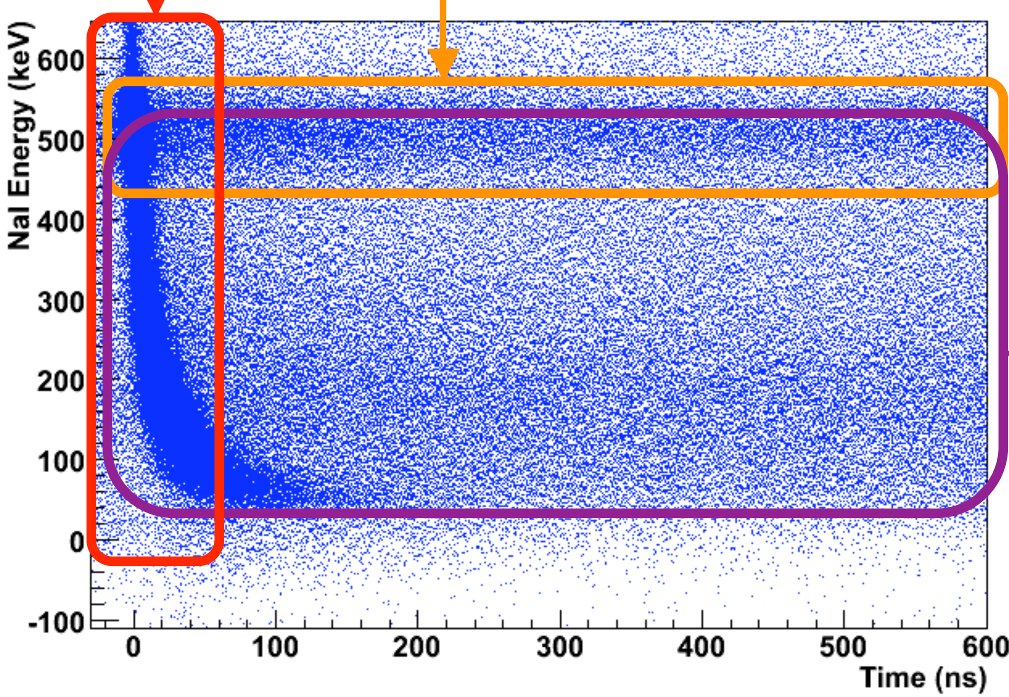
Source, holder & fibre +PMTs (TDC start)

NaI spectra



511keV prompts and accidentals: photo-electric

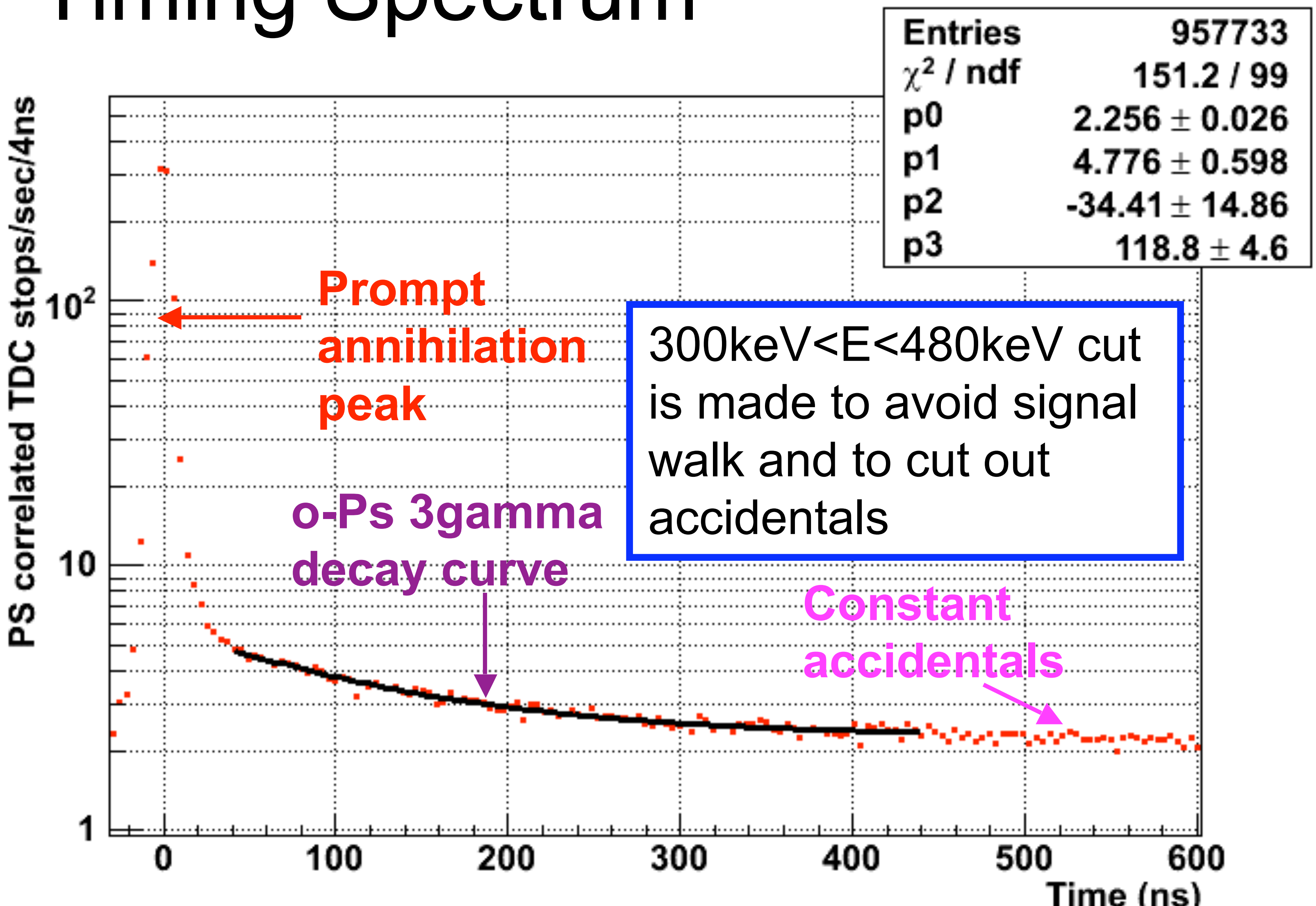
Prompt annihilation



511keV prompts and accidentals: compton deposits

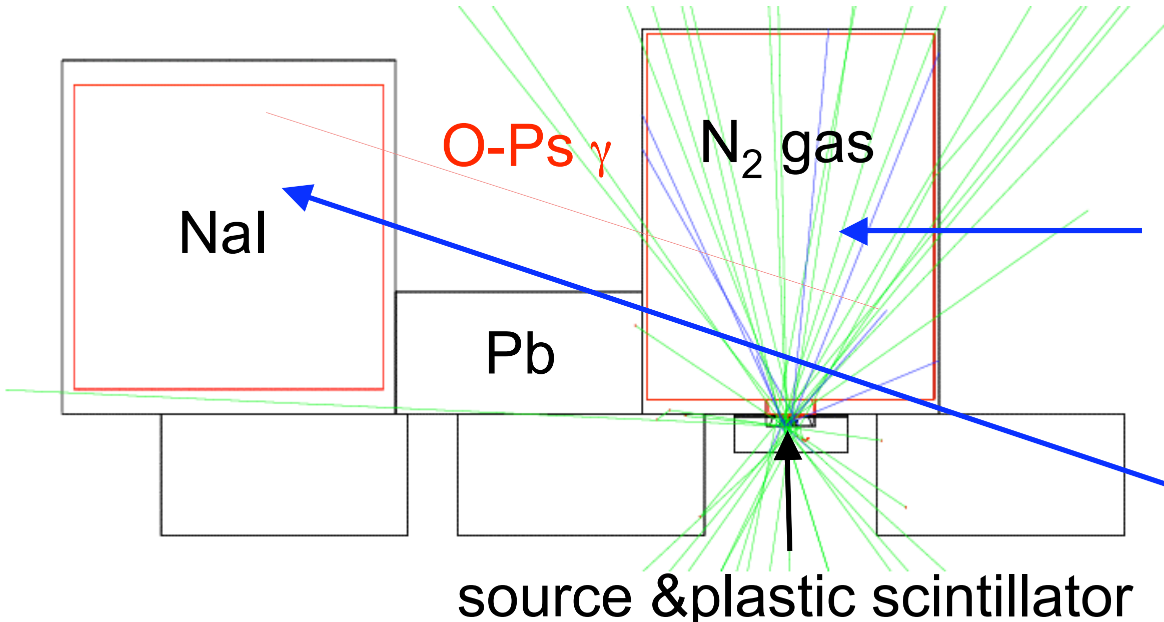
+ o-Ps 3gamma deposits

Timing Spectrum



Fitted o-Ps decay curve is integrated to calculate Ps creation efficiency in N2 gas

Simulation of Experiment



Measured o-Ps rate
= Positron tag rate
x gas stop fraction
x Ps creation eff.
x 3/4 (o-Ps fraction)
x NaI γ detection eff.
x energy cut factor

To calculate the Ps **creation efficiency** it is necessary to estimate the **blue** factors from MC simulation

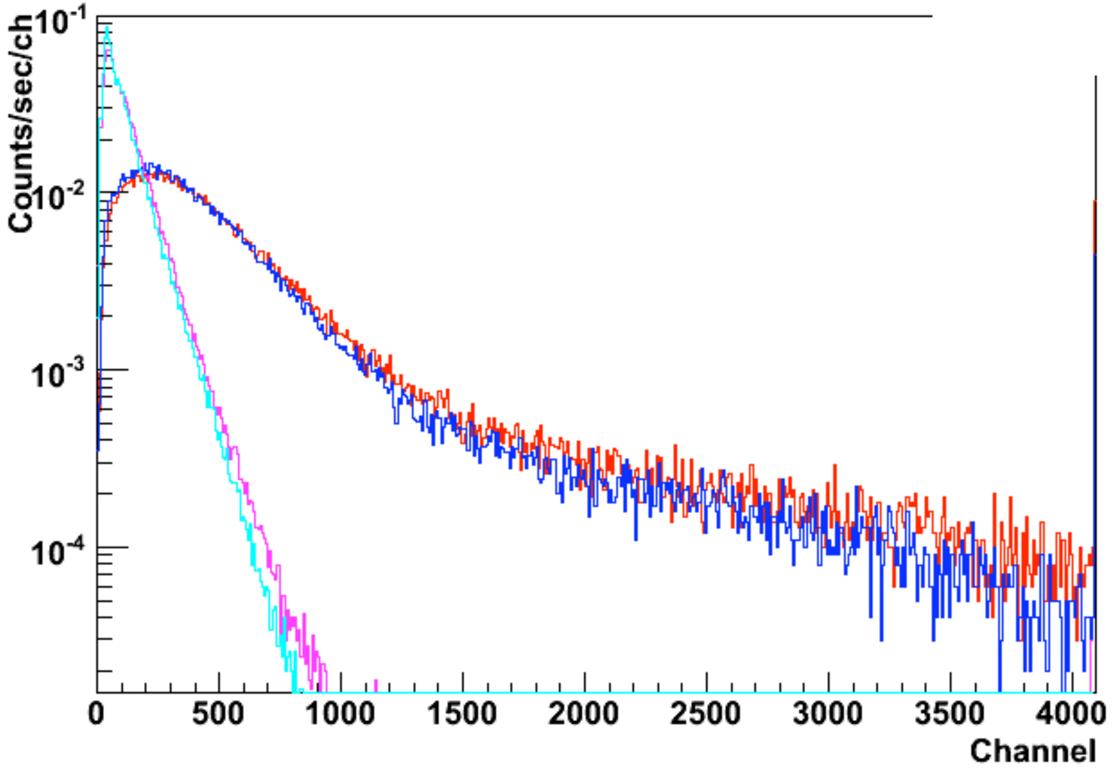
Of the tagged positrons:	
Stop in N_2	3.4%
& $\gamma \rightarrow$ NaI	0.12%
& 300keV<E_{NaI}<480keV	4.7×10^{-2} %

Combining the measured o-Ps and scintillator trigger rates with simulation data we arrive at a Ps creation efficiency in 1atm N_2 gas of 50% (preliminary). Some systematics are to be resolved.

Conclusion

- Ps production efficiency has been studied and cavity/positron tagging system design has been optimised for maximum Ps production.
    1. Cavity dimension are ϕ128mm & height 100mm
    2. Plastic Scintillator thickness is 200μm
    3. N_2 pressure < 2.0atm
- Positrons entering and stopping within the RF chamber are radially well confined due to the strong 0.8T B-field used in the experiment
    1. 96% of tagged and stopped positrons stop in r<6.4cm.
    2. 3.6% of tagged positron hit the top of the cavity.
- A positron tagging system using plastic scintillator fibre is expected to be implemented in the final experiment
- An preliminary result of 50% has been obtained for the creation efficiency of Ps in N_2 gas.

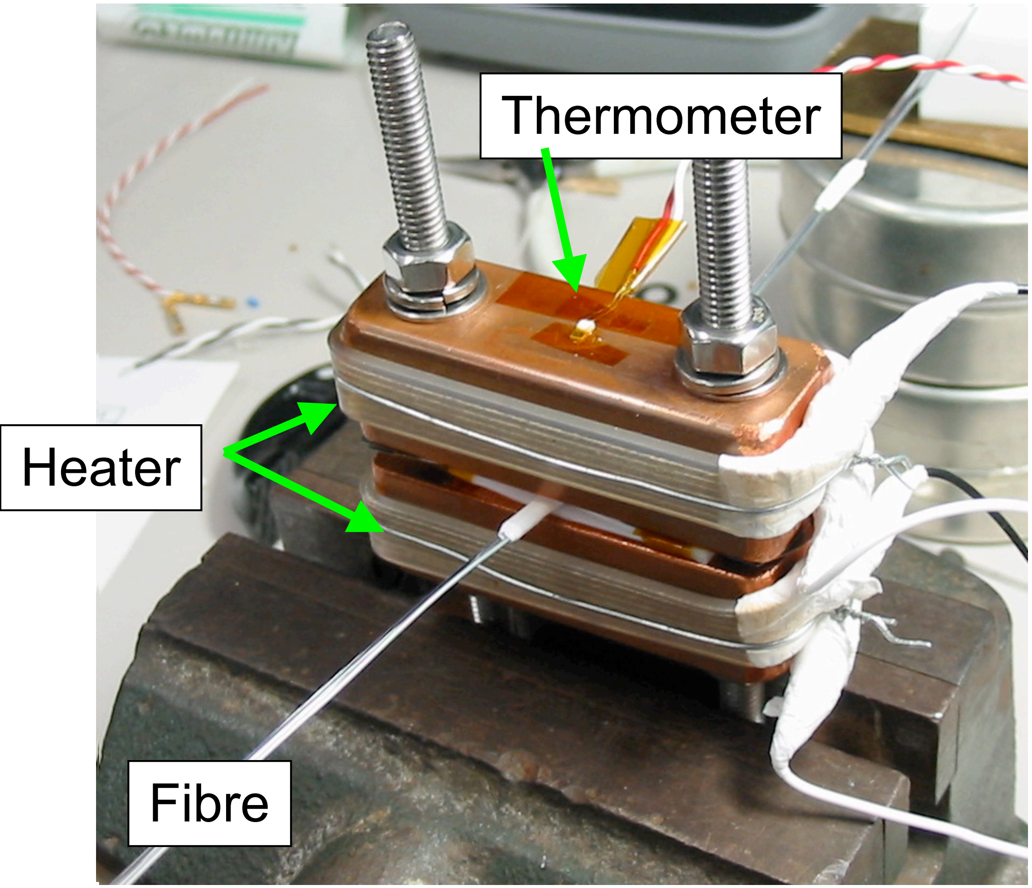
Backup (1)



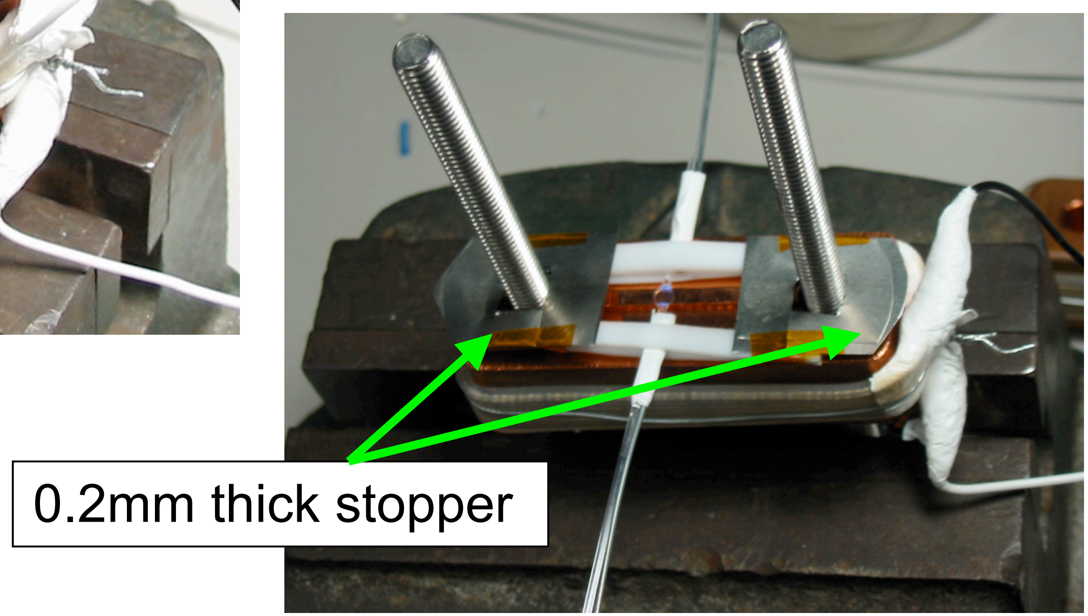
Drop in fibre light yield from being glued into place.
Single photoelectron level is 43 channels.

Backup (2)

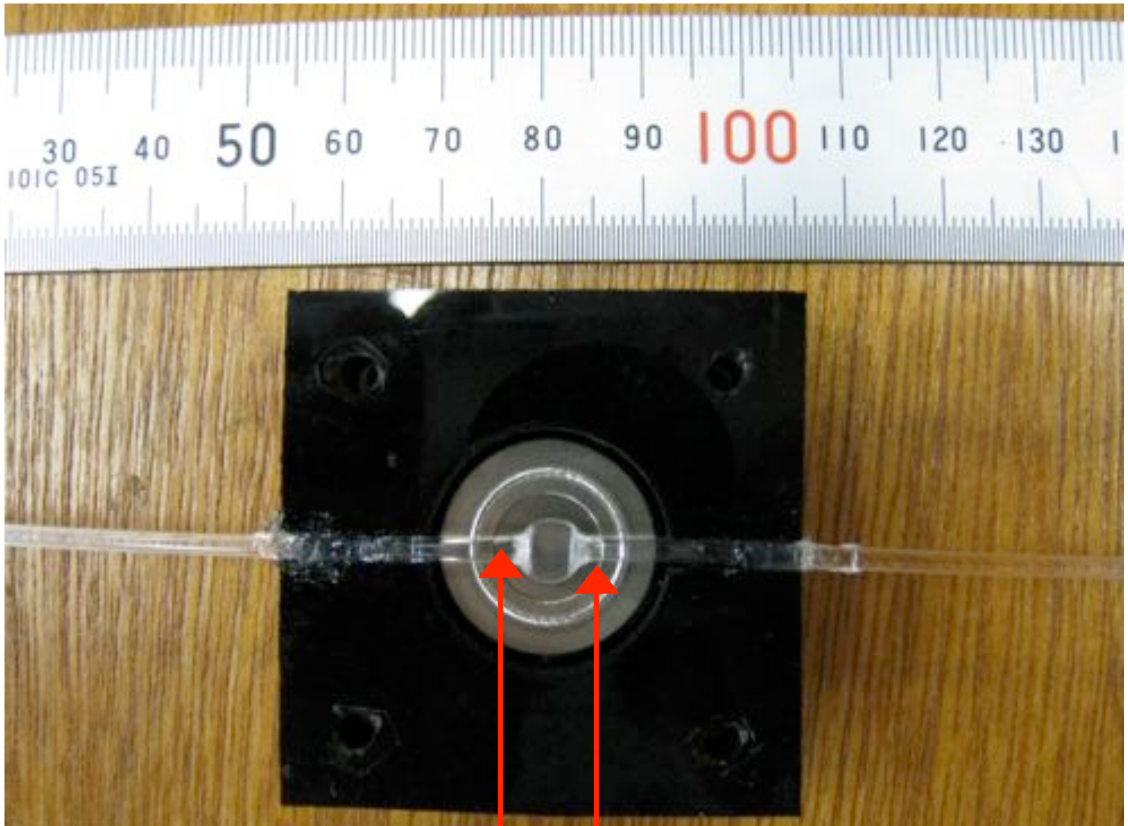
The PS fibre squashing process



After being squashed

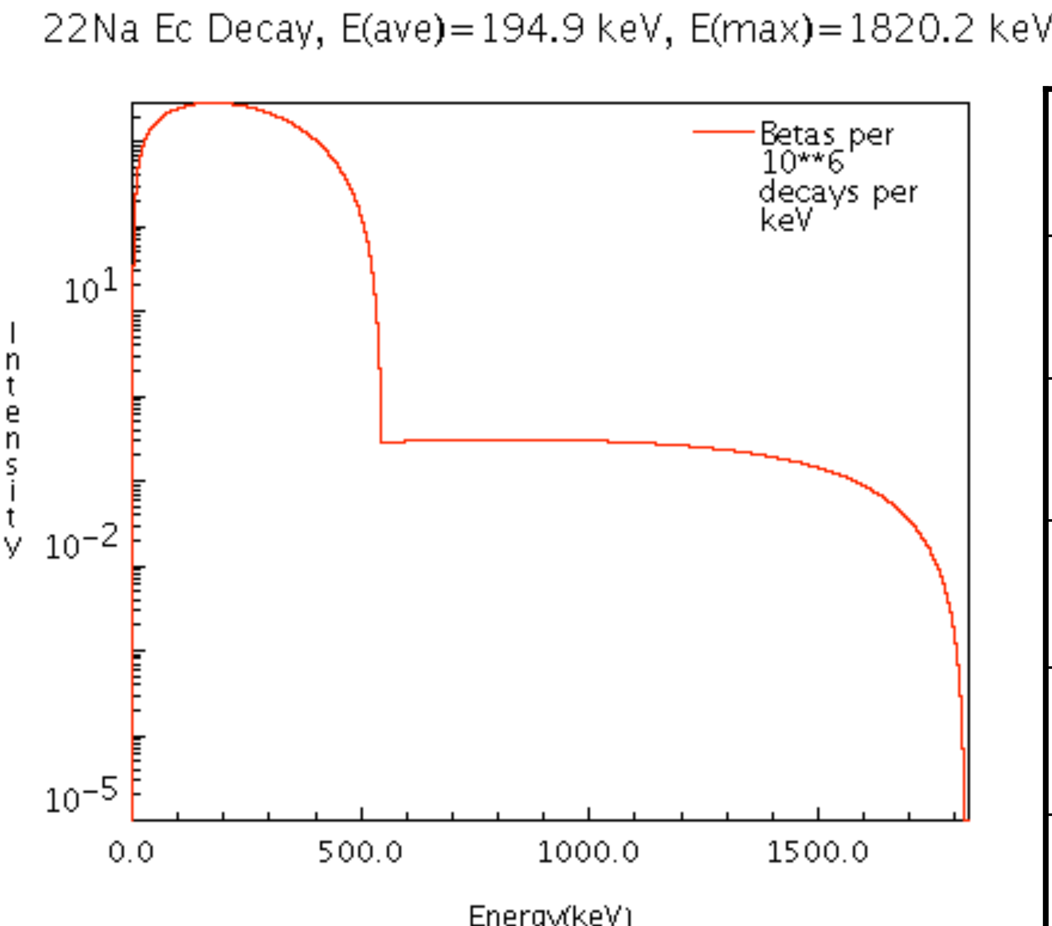


Backup (3)



A significant number of positrons passing through thick part of the fibre are tagged but don't enter chamber. This number is difficult to determine from MC simulation due to the geometry of the fibre. Plans are to use a collimator to resolve this.

Backup(4)



^{22}Na beta energy spectrum

Tagged positrons	38% of **all** positrons
Of tagged positrons:	
Stopped in cavity	19%
Stopped by plastic scintillator	67%
Hit the top of the cavity	3.6%
Stop elsewhere	10%