First test of O(α) correction on the energy spectrum in the orthopositronium decay

— Precise measurement on the energy spectrum of orthopositronium decay —

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Introduction

Orthopositronium (o-Ps) decay

- ✓ o-Ps decays into 3γ
- ⇒ Continuous spectrum
- ✓ S. Adkins has calculated this O(α) correction

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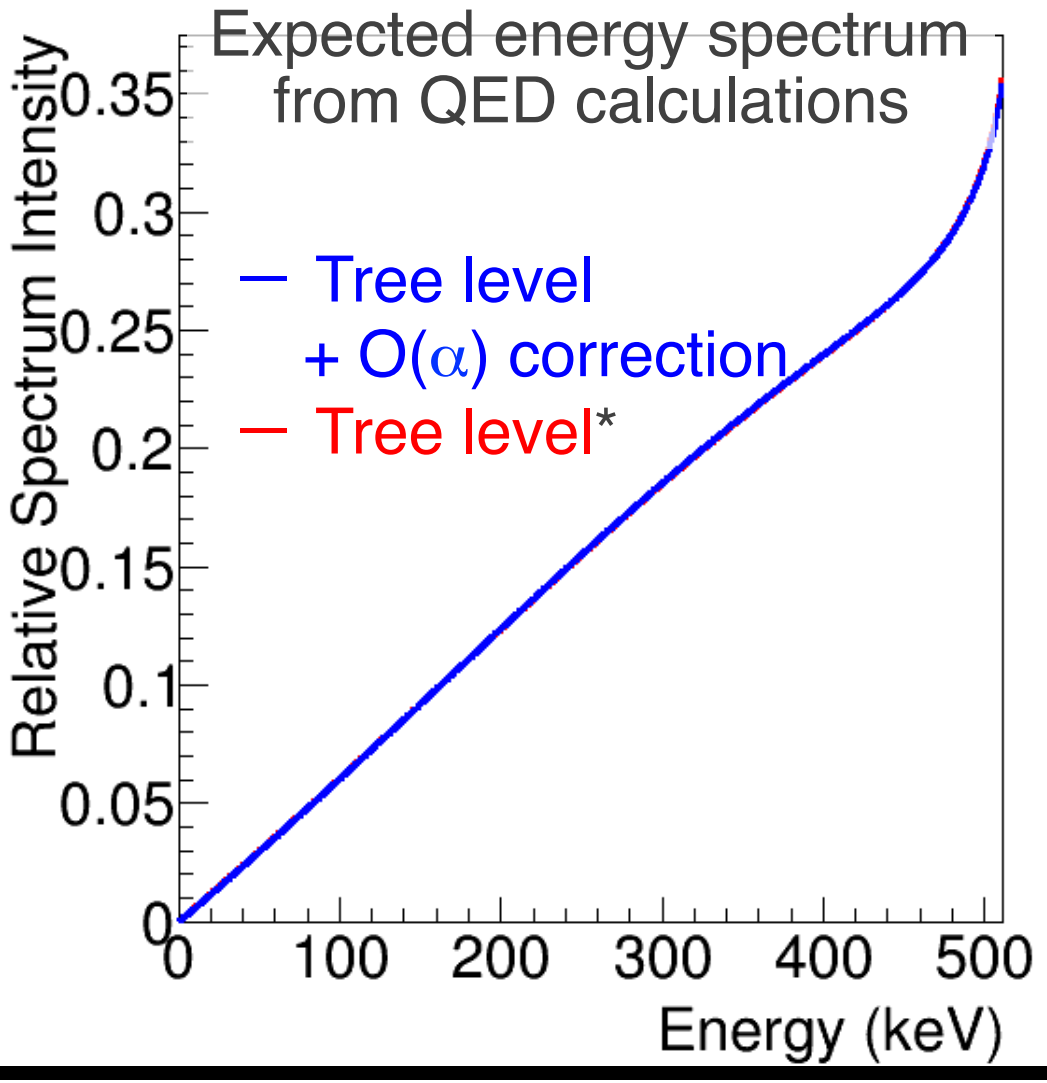
But, it is not examined by the experiment

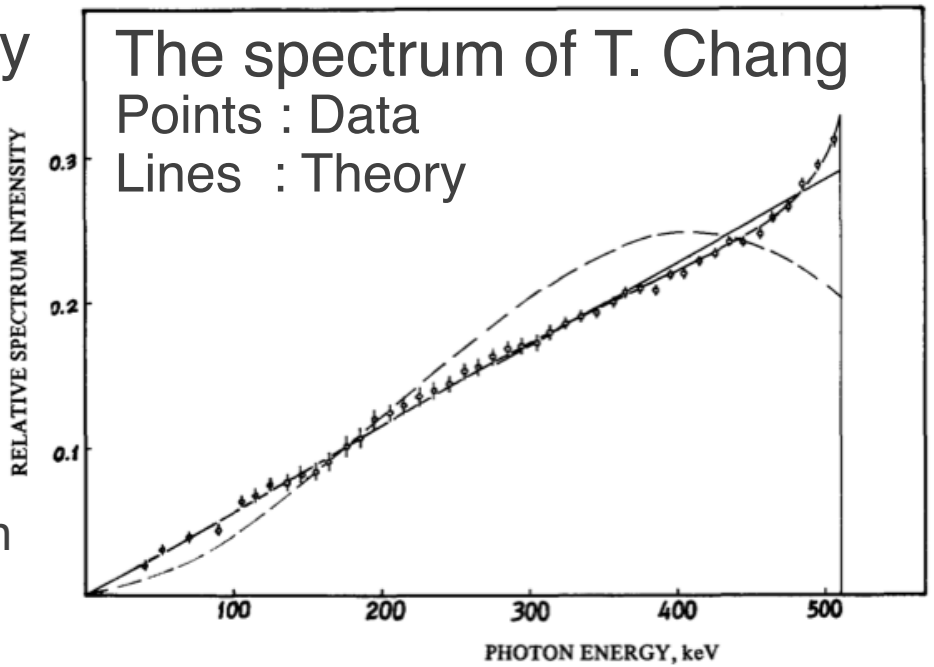
* The red line is also superimposed. But, it is very difficult to distinguish two spectra.



✓ The spectrum was measured by *T. Chang et al.* (Phys. Lett. B 157 (1985) 357-360)

But, the experimental precision was **not enough** to observe the O(α) correction

So nobody examined the O(α) correction



✓ The O(α) corr. has been checked in the o-Ps decay rate (Y. Kataoka et al. Phy. Lett. B 671 (2009) 219-223)

But, the spectrum has more detail information than o-Ps decay rate

since o-Ps decay rate has only the integral information of the spectrum

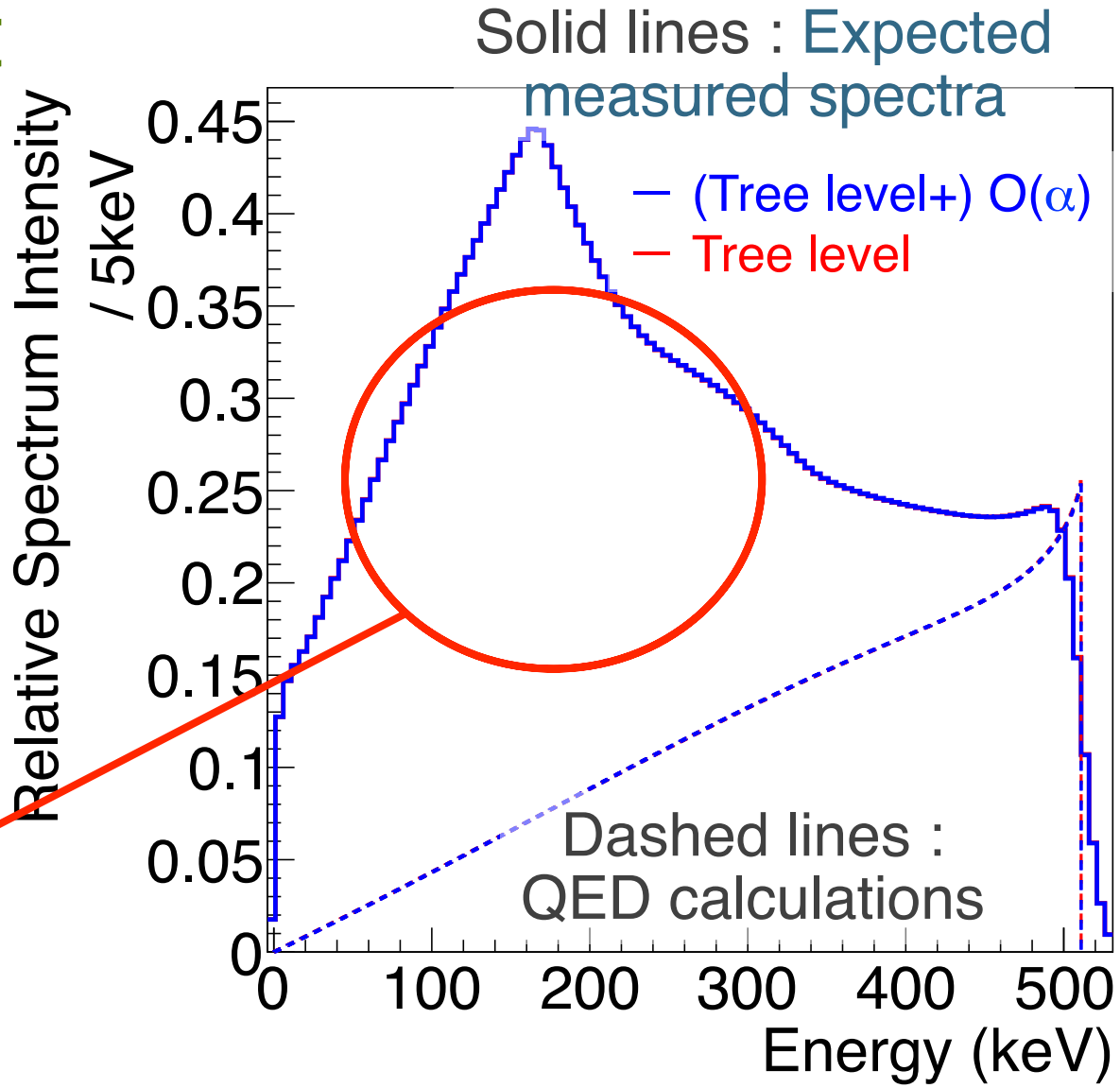
⇒ We want to check the O(α) corr. also in the energy spectrum

It is very difficult to test the O(α) correction. There are two reasons...

1. Material effect

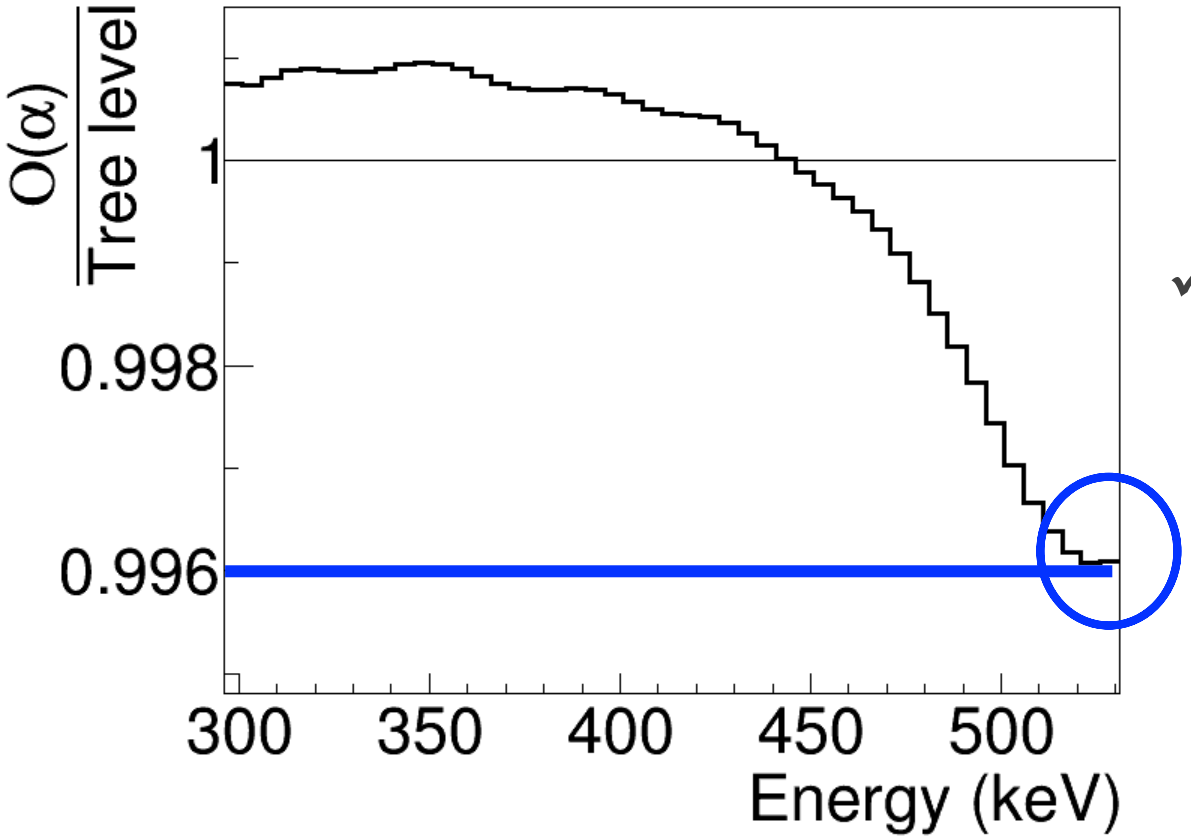
- ✓ A measured spectrum is <u>much distorted</u> by **the detector response** and **materials** like the solid lines

<u>Compton scattering</u> has serious effect. It distorts the spectra especially in <u>the low energy region</u>.



2. The O(α) corr. is too small

The ratio of
the expected measured spectra
(O(α) / tree level)



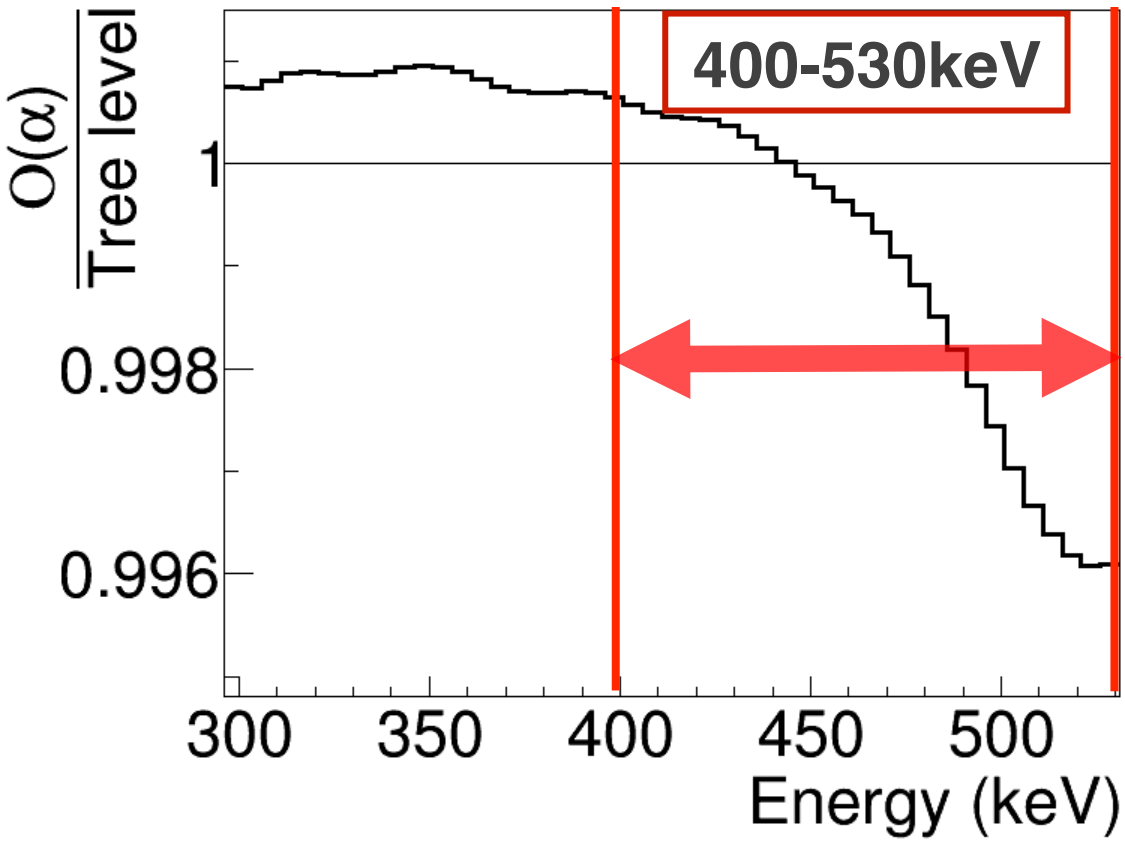
✓ The max O(α) corr. :

only 0.4%!

too small!

Energy region used to test the O(α) correction

The ratio of
the expected measured spectra
(O(α) / tree level)



We used the energy region of **400-530keV** because

1. The O(α) corr. is large
2. This region is less affected by **Compton scattering**

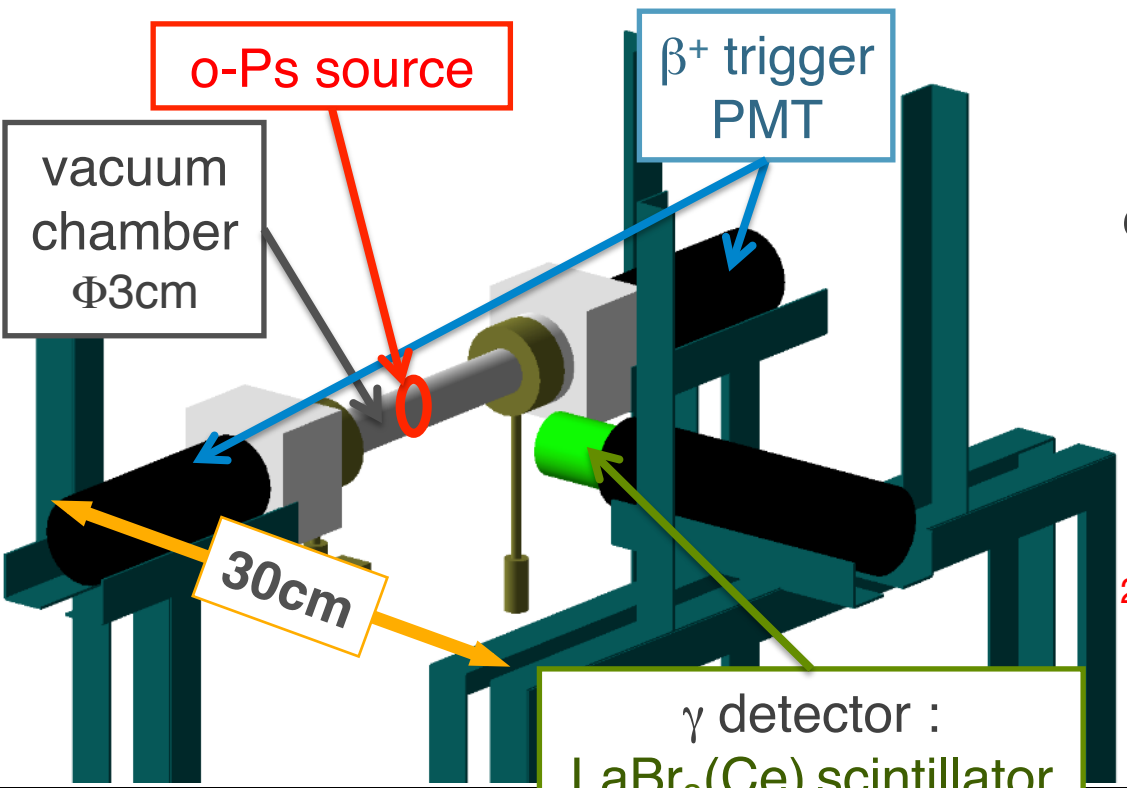
   It distorts the low energy region

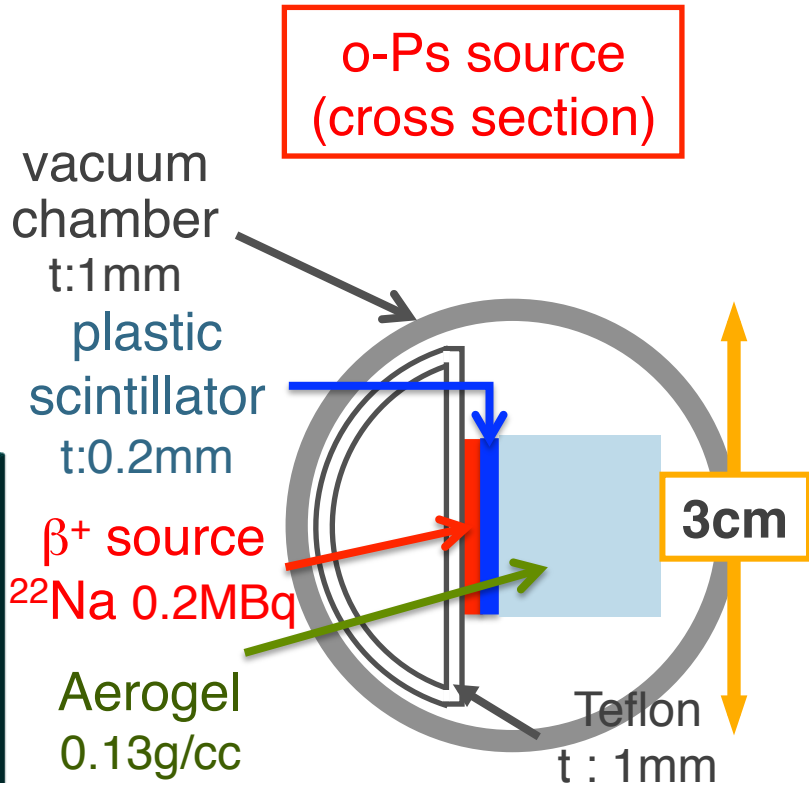
Experimental setup

Experimental setup

To suppress material influences, we paid attention to two points

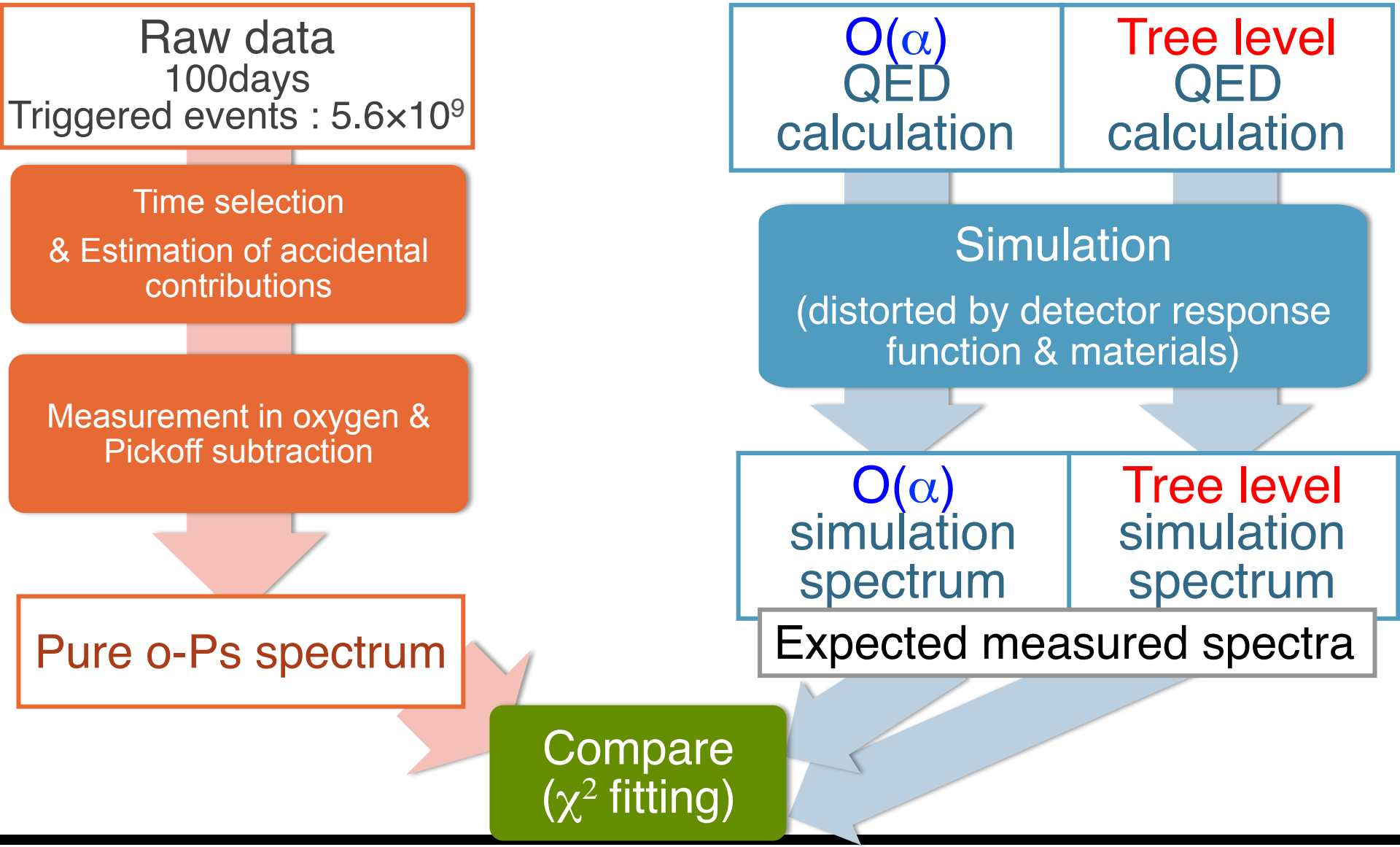
- ✓ Keep the whole setup 1m away from the floor and walls
- ✓ Reduce the materials as much as possible
  Especially, the o-Ps source region has low material density



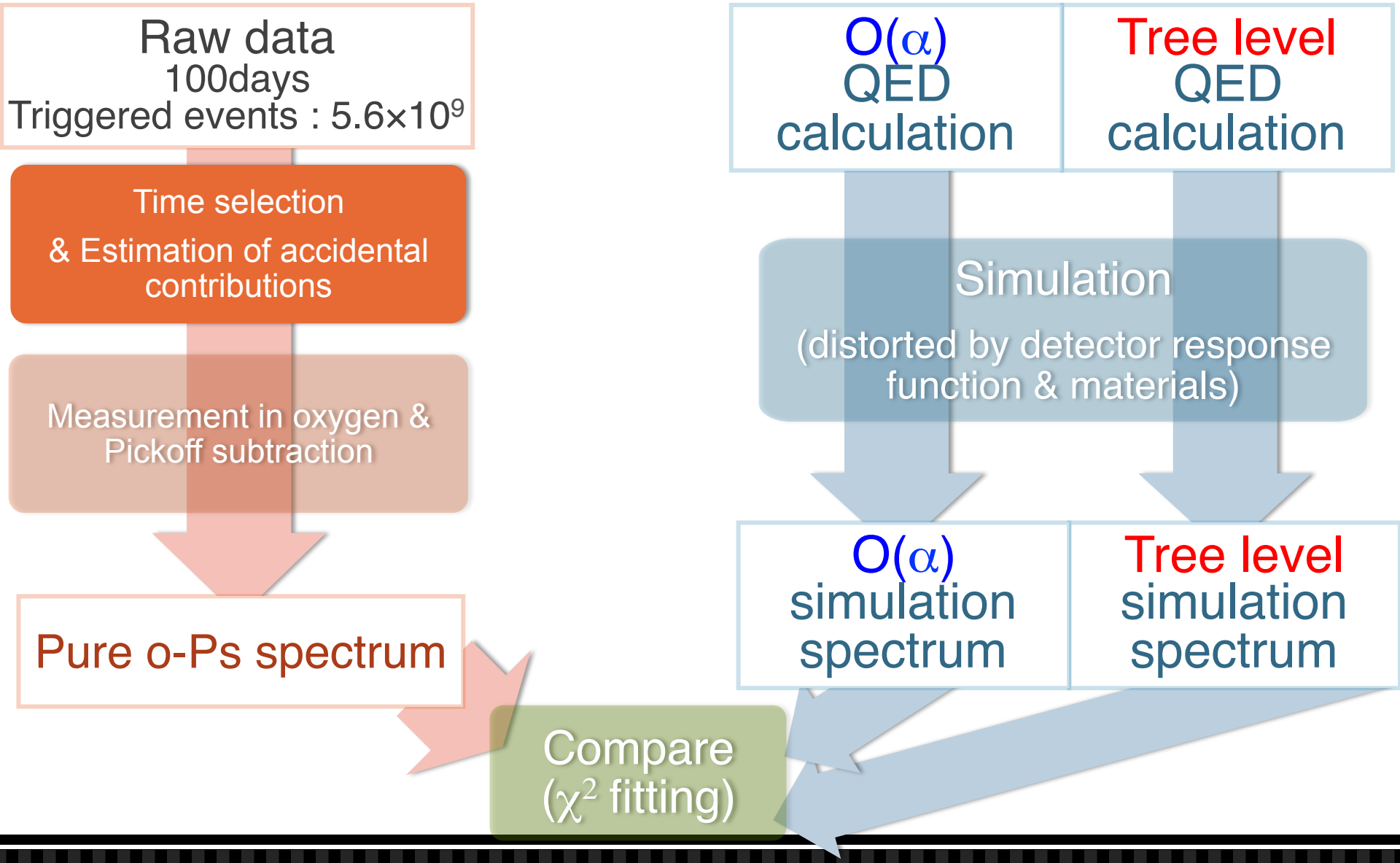


Analysis

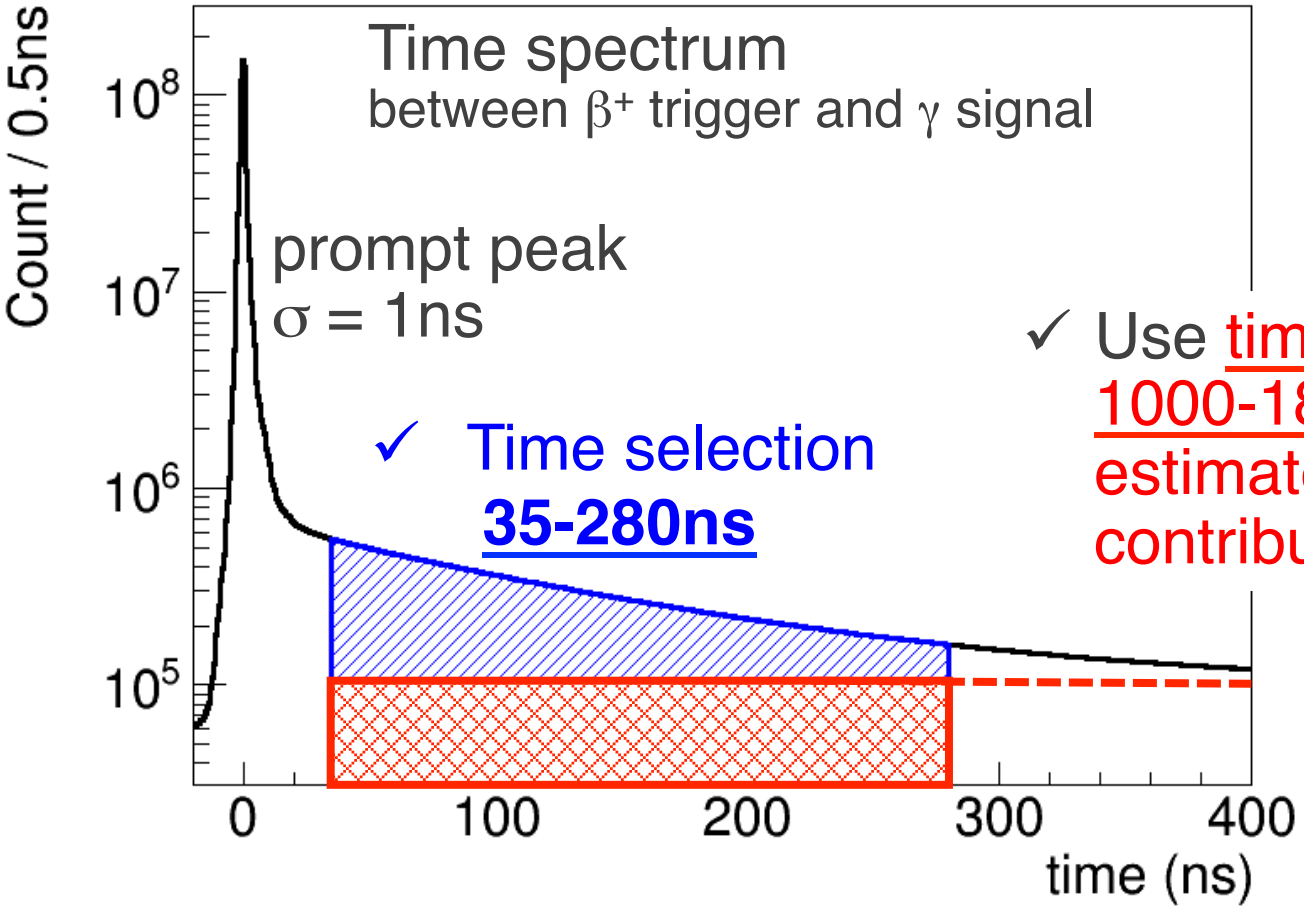
Analysis flow chart



Analysis flow chart



Time selection & Estimation of accidental contributions

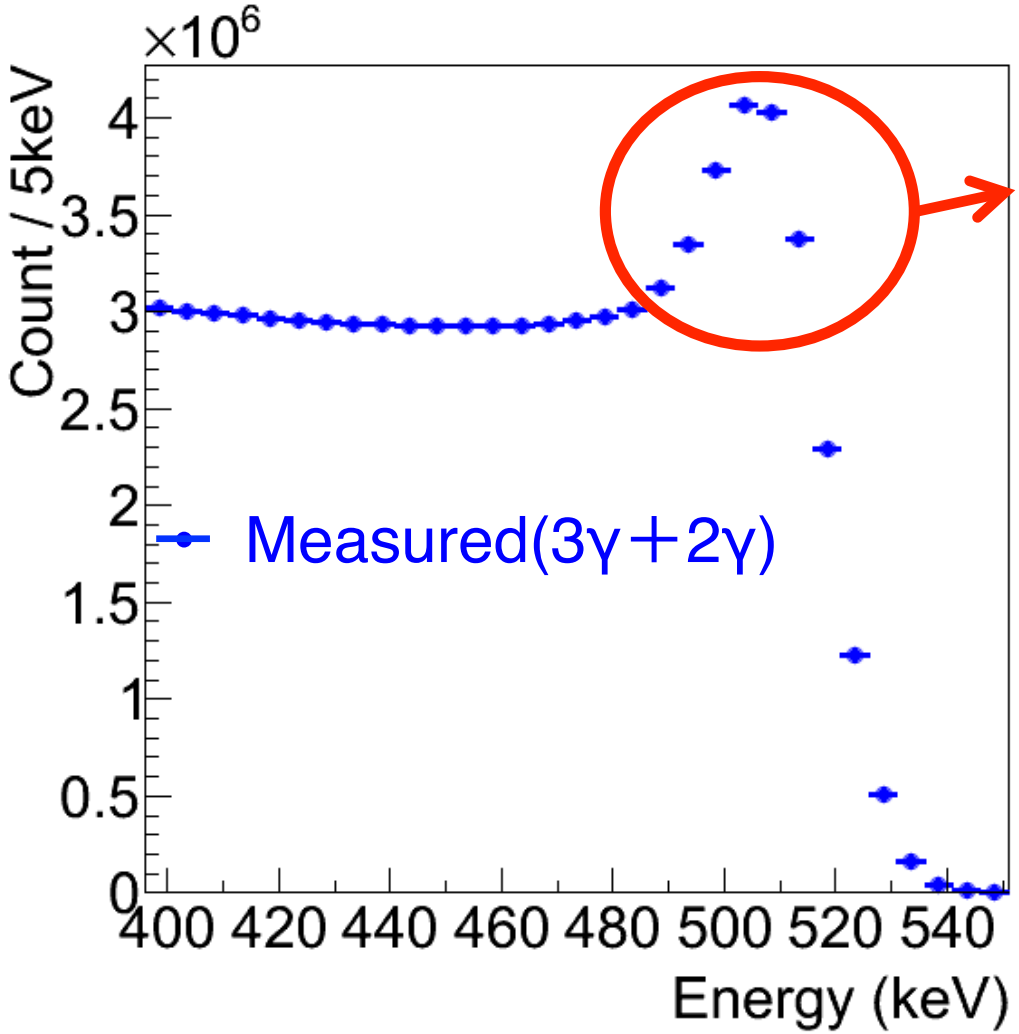


✓ Time selection **35-280ns**

✓ Use time window of 1000-1800ns to estimate accidental contributions

Measured lifetime : **129.5±1.5ns**

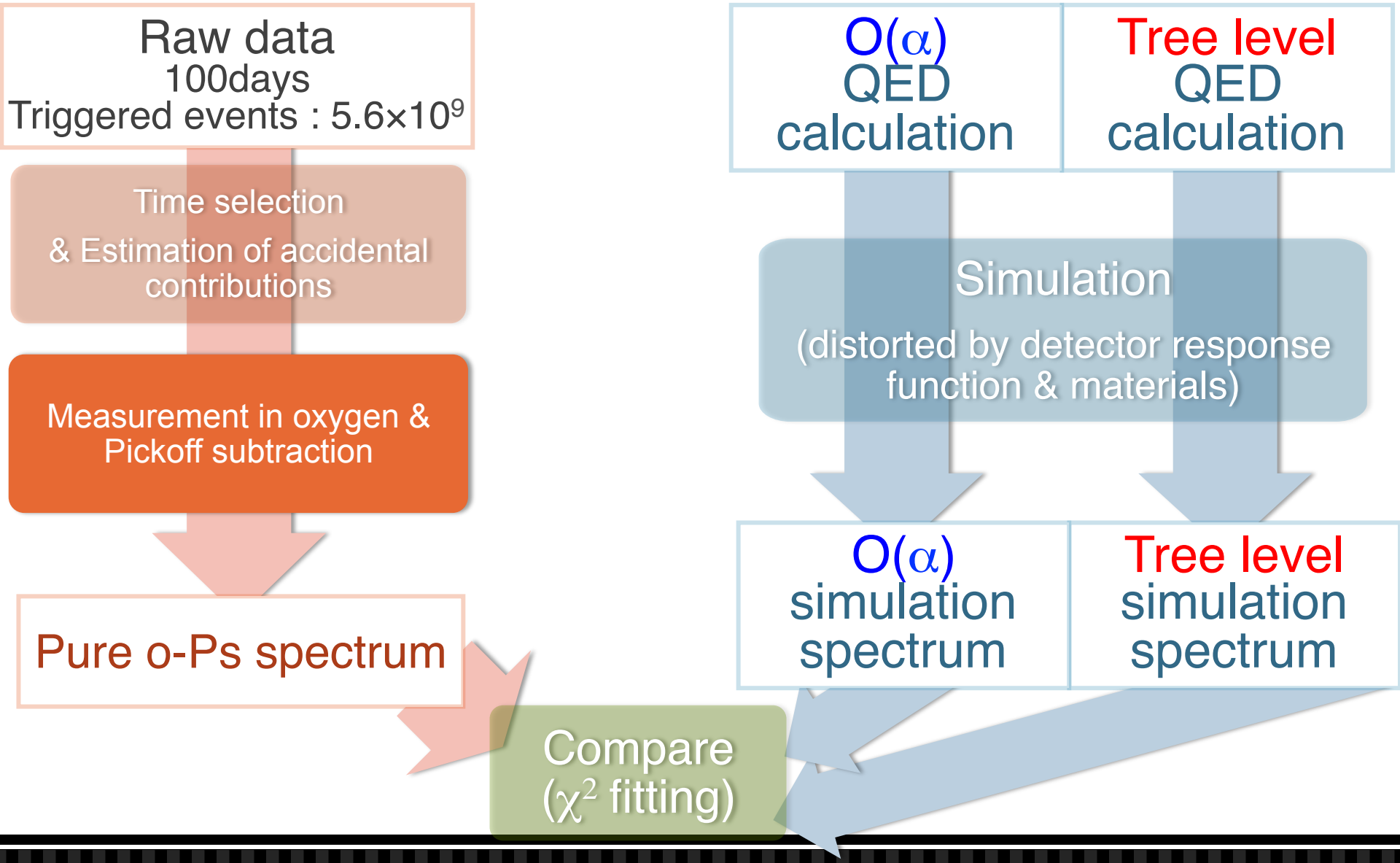
Energy spectrum
after time selection & estimation of accidental



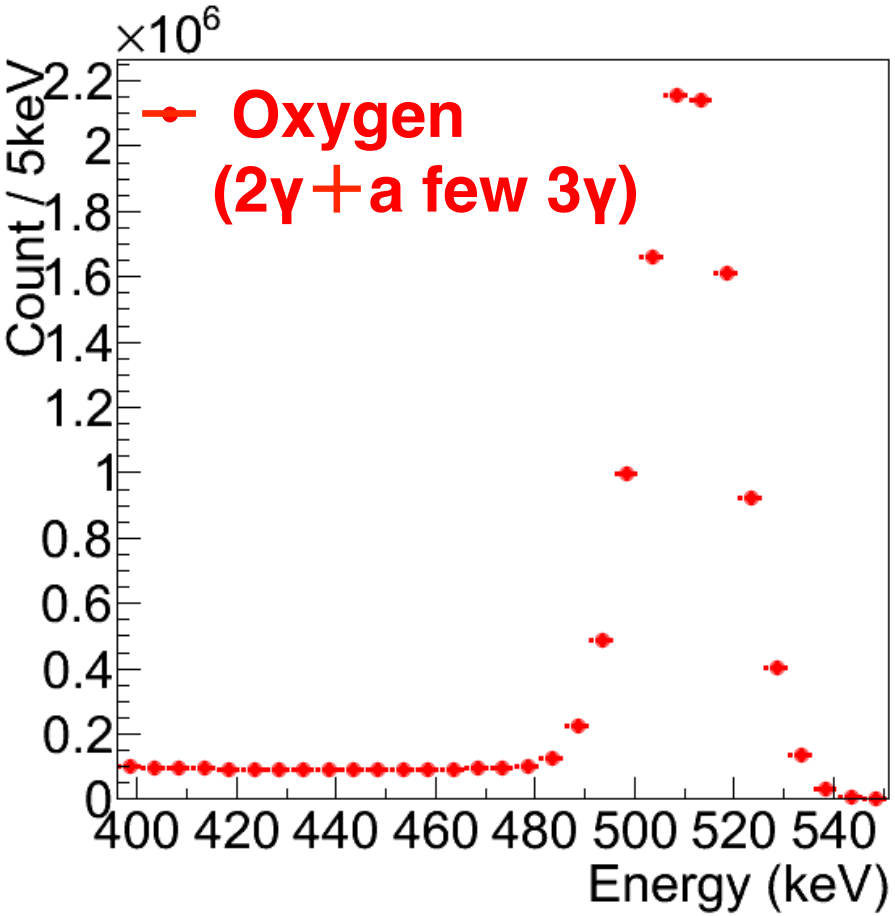
✓ This spectrum has a peal at 511keV from 2γ decay of "pickoff annihilation"

⇒ This is crucial background!

Analysis flow chart



Measurement in oxygen gas



We measured energy spectrum in 1atm oxygen gas with the same setup

- ✓ Oxygen causes spin conversion into 2γ

  ⇒This spectrum has much 2γ decay

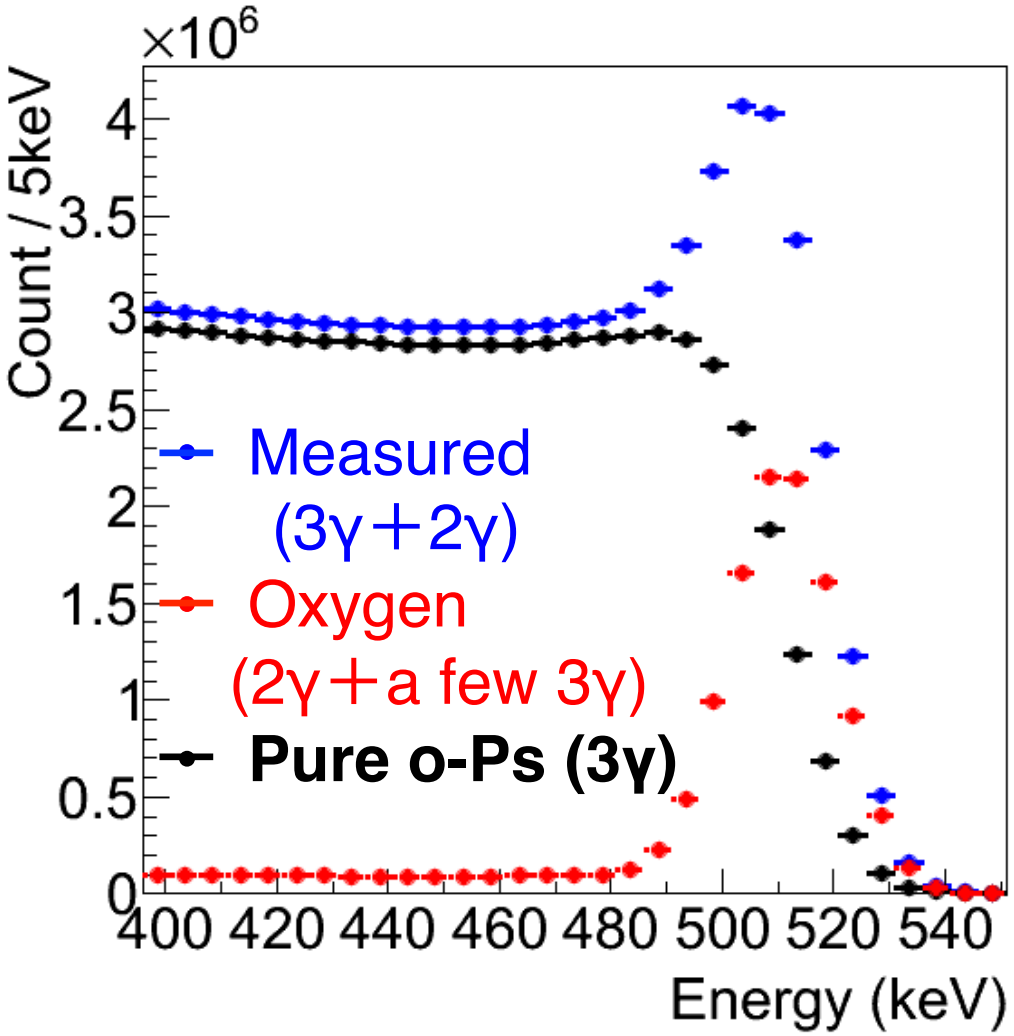
However,

- ✓ Pickoff has broader peak-width than spin conversion

We corrected the peak-width by using the measured values written in the following papers

- S.Orito, *et al,* PRL 63 (1989) 597-600
- S. Asai, *et al,* PRL 66 (1991) 1298-1301

Pickoff subtraction

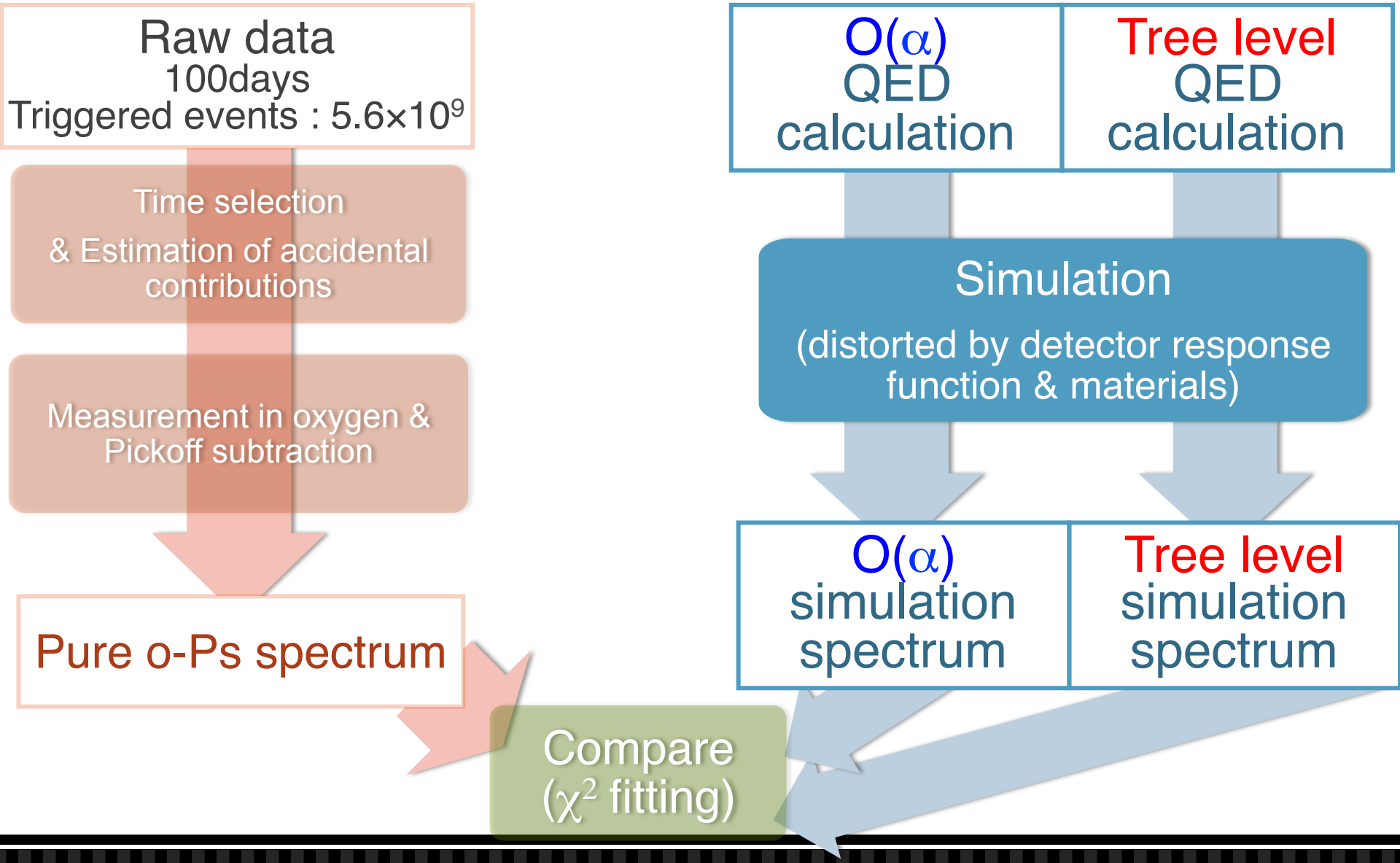


To subtract 2γ decay of pickoff annihilation,

Pure o-Ps spectrum

= Measured – Oxygen

Analysis flow chart

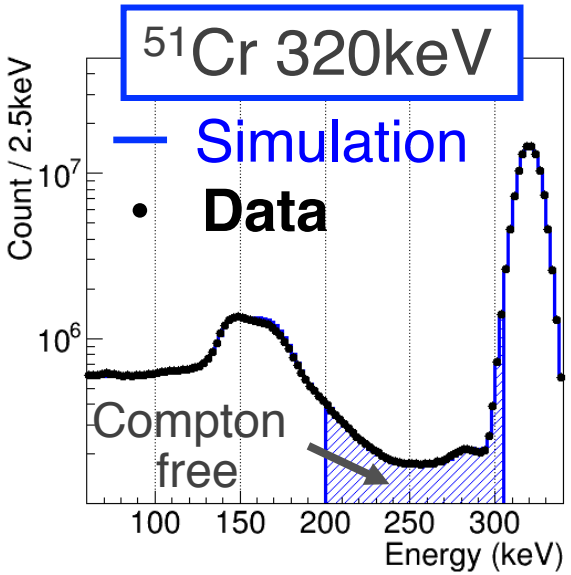


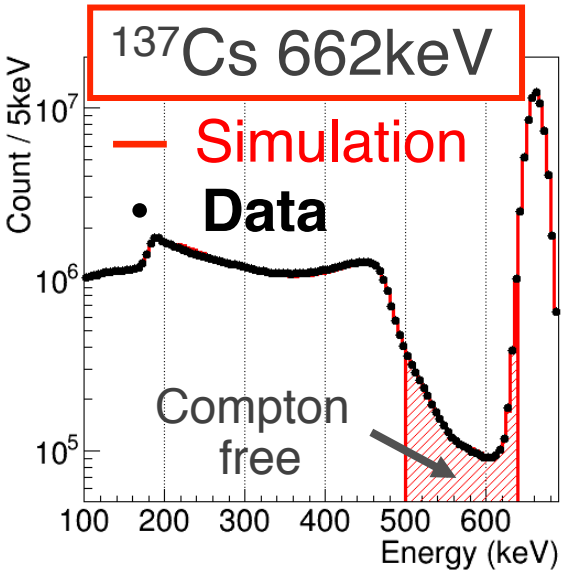
Simulation

- ✓ Use GEANT4 Monte Carlo simulator
  popular in particle and nuclear physics
- ✓ Simulate all the passages and reactions of γ-ray through matters
- ✓ Generate 2 spectra for O(α) and tree level QED calculations
- ✓ We measured **two mono-energetic γ sources**
  to estimate accuracy of this simulation

Both simulations well describe measured data!

The max discrepancy is only 3.7% in Compton free region





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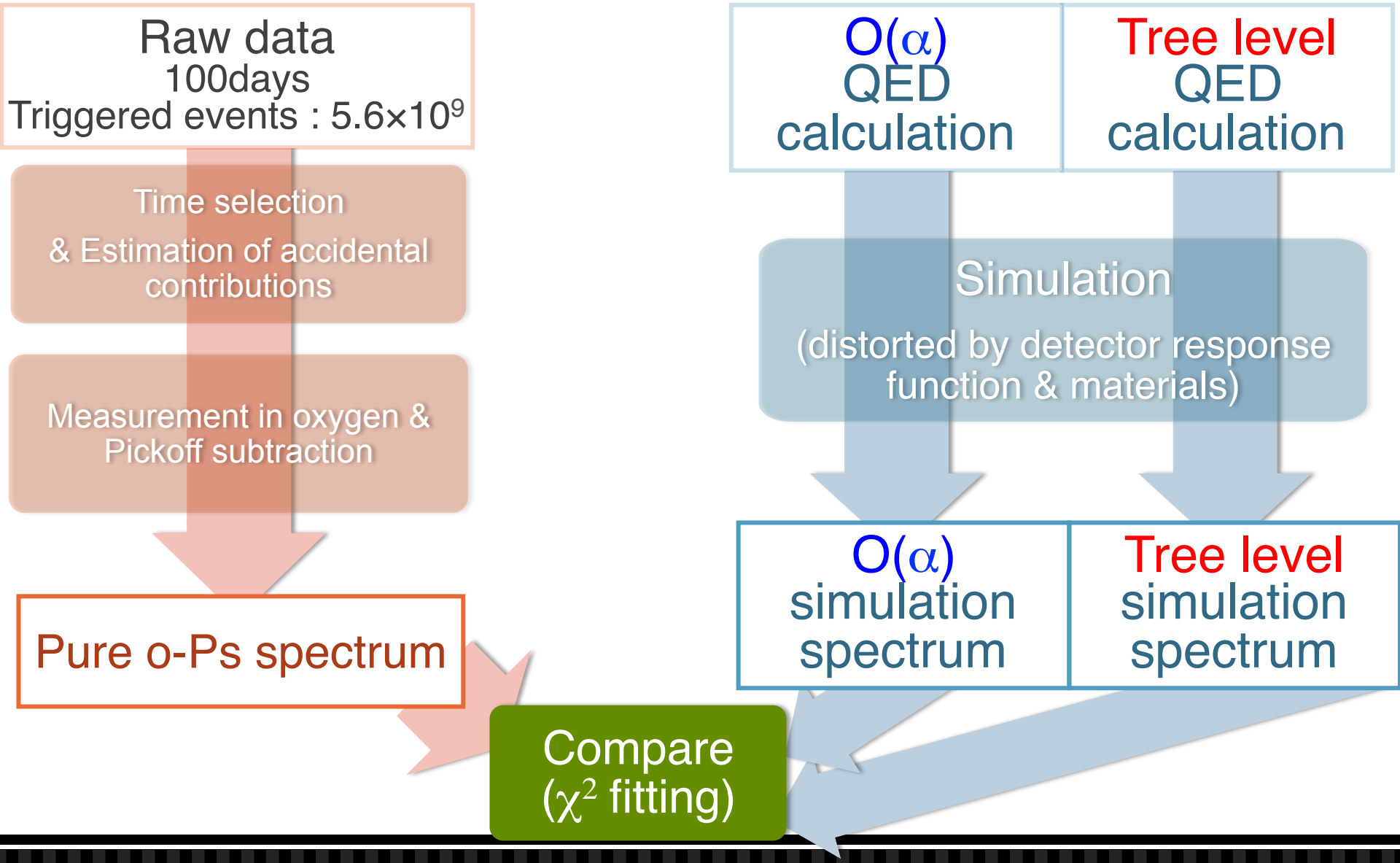


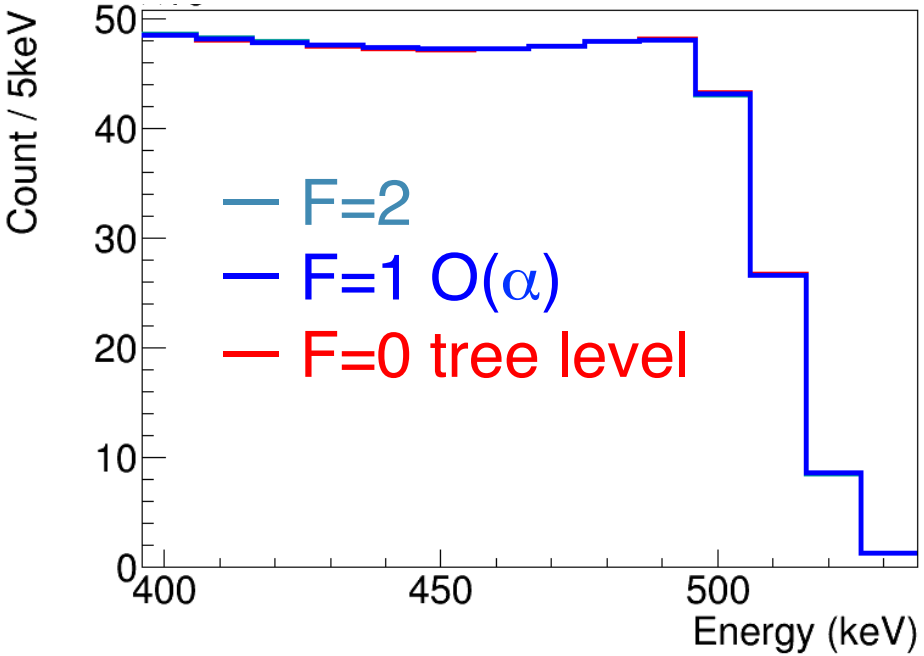
Method in χ^2 fit of pure o-Ps spectrum & simulation spectrum

Introduce a free parameter **F** in the simulation spectrum

Simulation spectrum =

F×O(α) simulation spectrum + (1-**F**)×Tree level simulation spectrum

Simulation spectra at some F values



- F is the mixing amount of O(α) & tree level
- F is fitted* to pure o-Ps spectrum with χ^2 method

  F = 1 : O(α)
  F = 0 : Tree level

- Fitting region is 400-530keV

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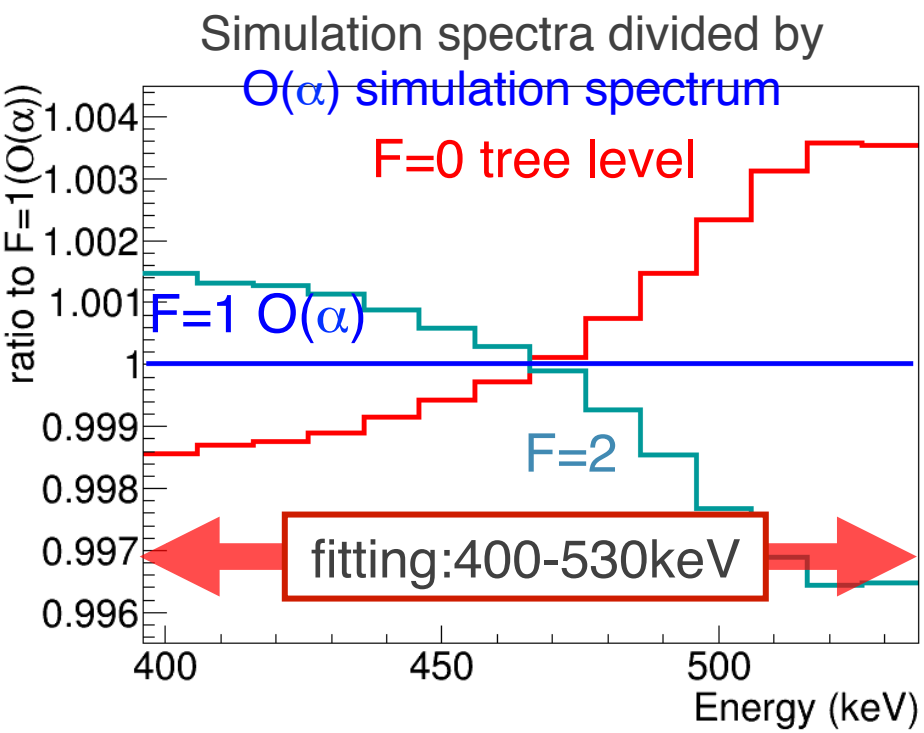

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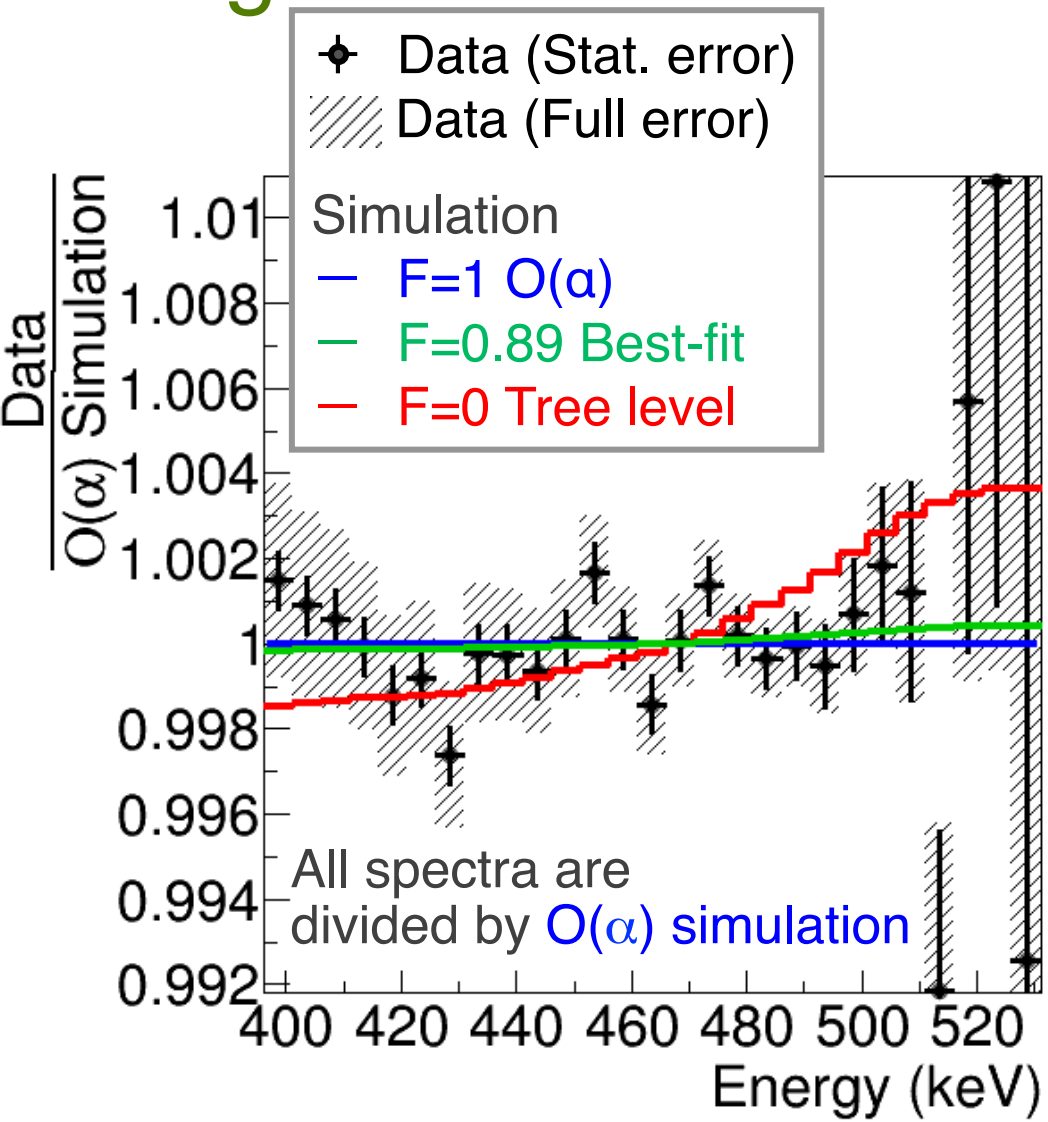
Fitting result



χ^2 / n = 16.2 / 23

F = **0.89 ± 0.61**

(@68.3% C.L.)

F= 0 is excluded at 94.0%C.L.

Data (measured spectrum) is consistent with the blue line and completely inconsistent with the red line

Summary

Summary

- ✓ We **first** observed the O(α) correction in the energy spectrum of o-Ps decay
- ✓ This result supports the O(α) correction and excludes tree level energy spectrum at 94% C.L.