

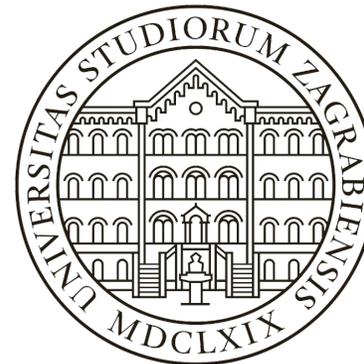
Search for the CP symmetry violation in the OPSVIO project

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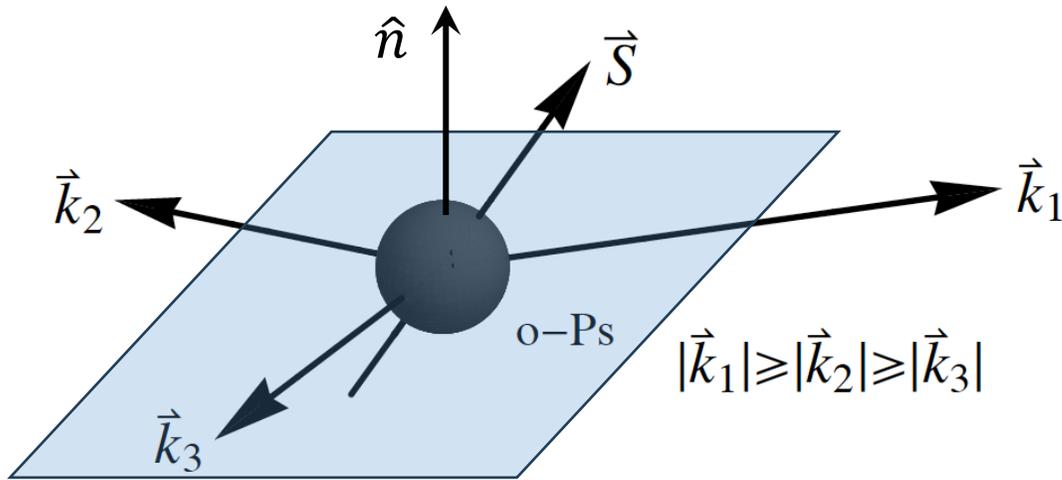
University
of Zagreb

CP symmetry

CP symmetry violation – important in explaining matter-antimatter asymmetry

- measured in hadron sector
- indication of violation in leptonic sector (K. Abe, et al., Nature 580, 339–344 (2020))
- Ortho-Positronium decay no violation at the 10^{-3} level (T. Jamazaki et. al., PRL 104, 083401 (2010))

Search for CP violation better than 10^{-3}



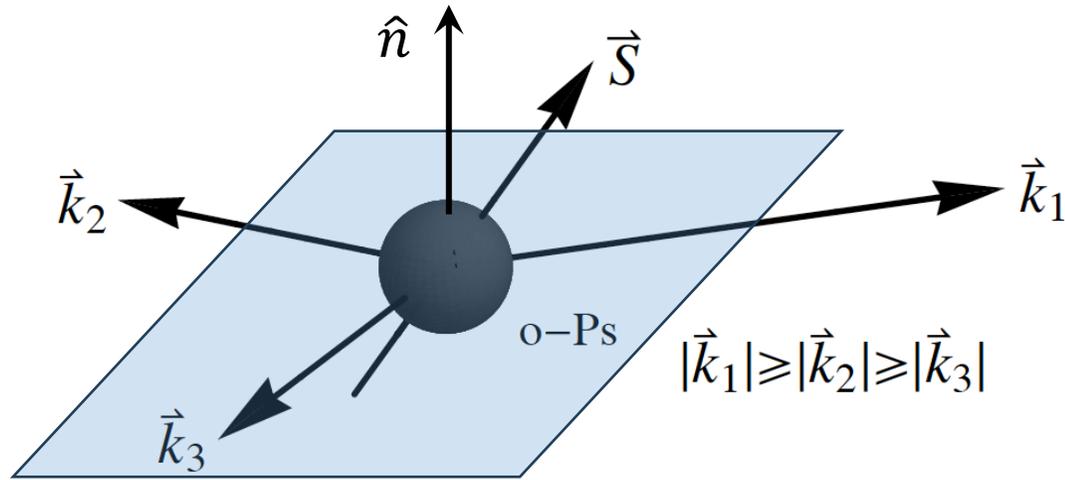
\vec{S} – o-Ps spin direction
 $\vec{k}_{1,2,3}$ – momentum vectors of annihilation photons

Table 1. Discrete symmetry properties of the correlation operators.

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

G.S. ADKINS, CPT and Lorentz Symmetry, pp. 254-257 (2010)

Search for CP Violation in Positronium Decay, T. Jamazaki et. al., PRL 104, 083401 (2010)



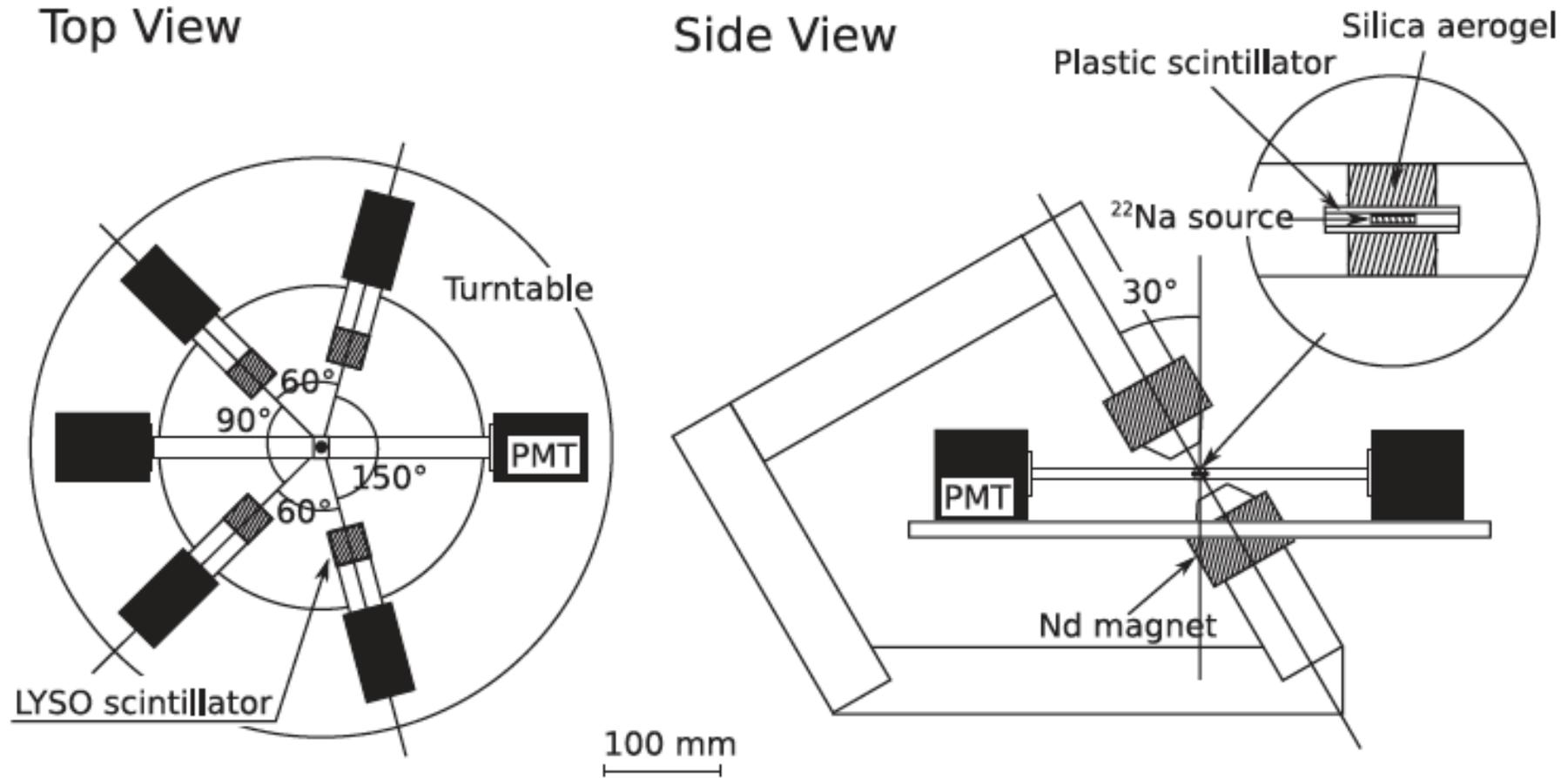
- θ – angle between \hat{n} and \vec{S} of the o-Ps
- ψ – angle between \vec{k}_1 and \vec{k}_2
- ϕ – angle between \vec{k}_1 and projection of \vec{S} onto the o-Ps decay plane
- θ and ψ are fixed \rightarrow CP violation appears as asymmetric function of $C_{CP}Q(\phi)$
- P_2 – spin alignment of o-Ps \rightarrow tensor polarization

$$N = N_0[1 + C_{CP}(\vec{S} \cdot \vec{k}_1)(\vec{S} \cdot \vec{k}_1 \times \vec{k}_2)] \exp(-t/\tau)$$

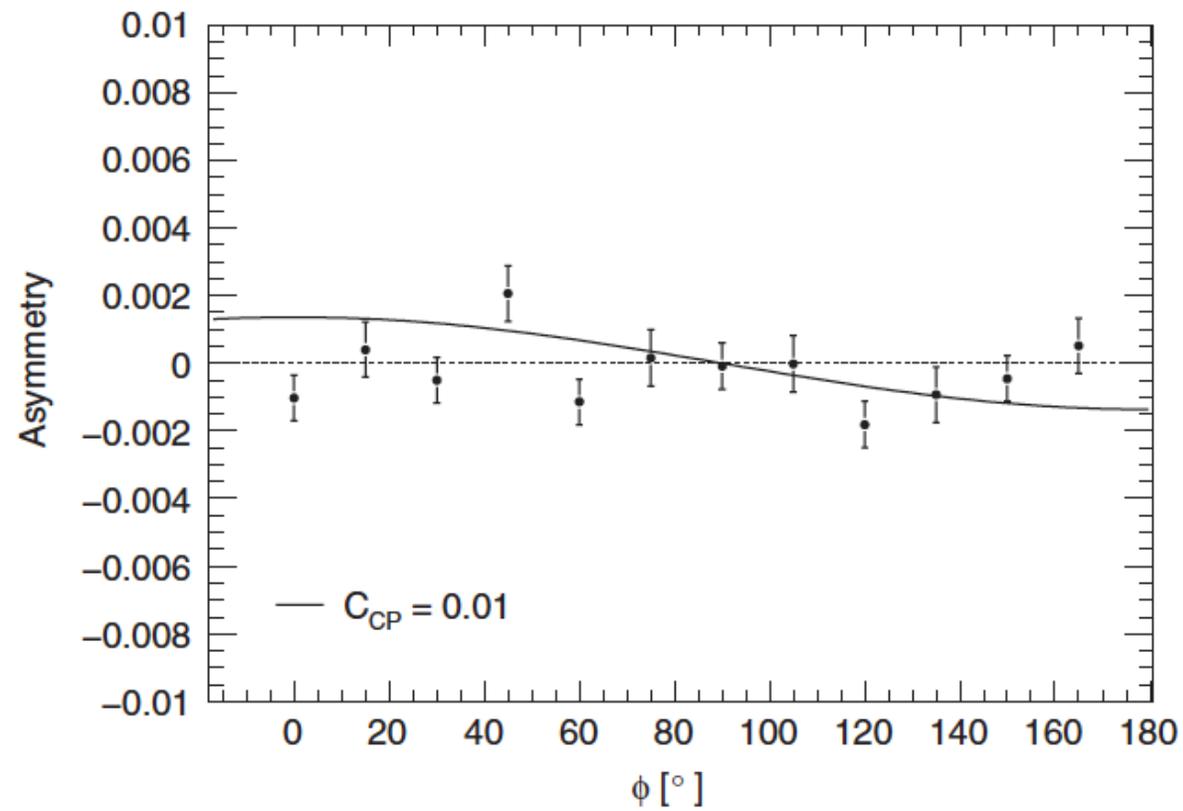
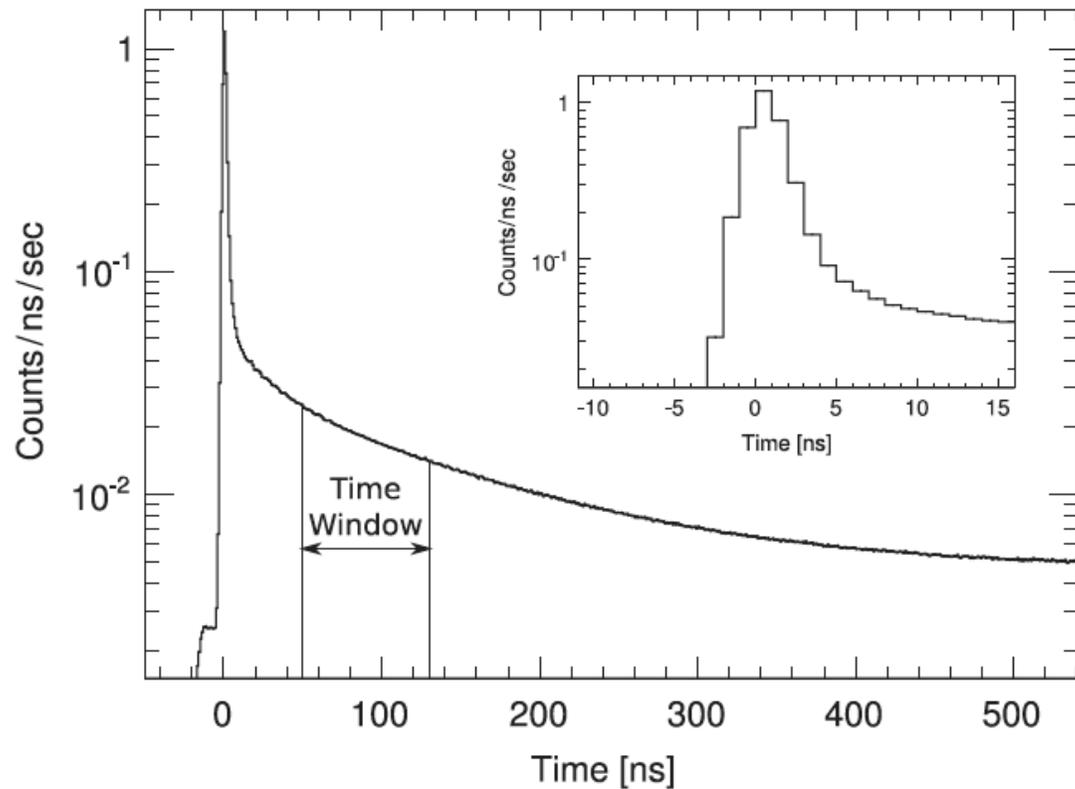
$$Q = (\vec{S} \cdot \vec{k}_1)(\vec{S} \cdot \vec{k}_1 \times \vec{k}_2) = P_2 \sin 2\theta \sin \psi \cos \phi$$

$$P_2 = \frac{N_{+1} - 2N_0 + N_{-1}}{N_{+1} + N_0 + N_{-1}}$$

Search for CP Violation in Positronium Decay, T. Jamazaki et. al., PRL 104, 083401 (2010)



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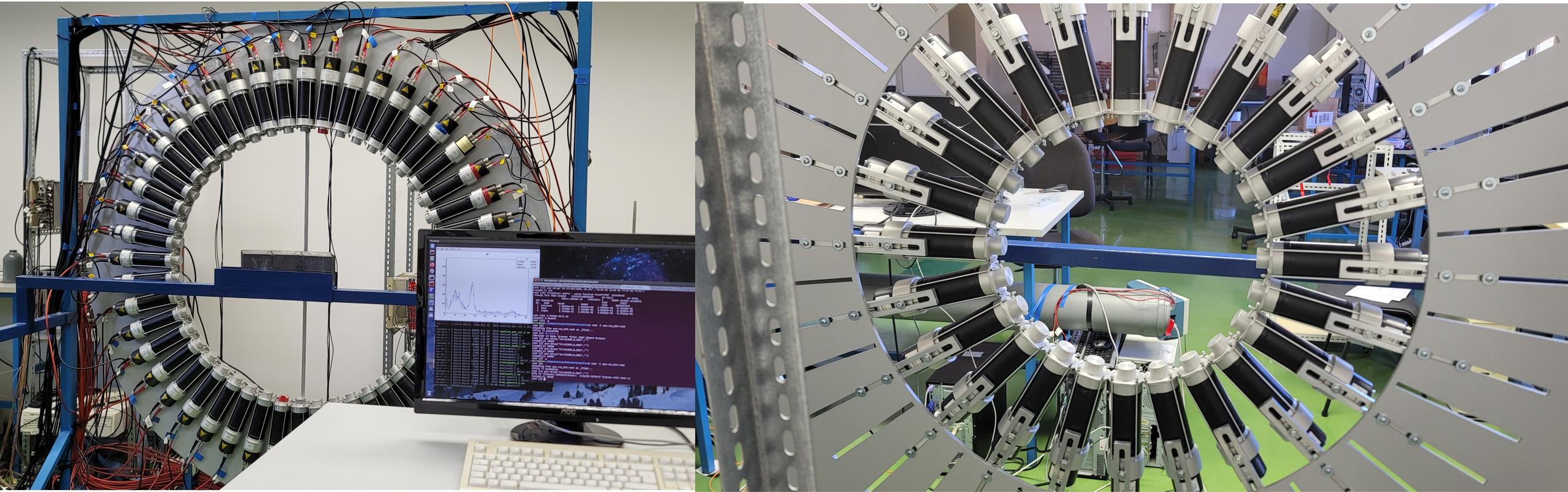
Search for CP Violation in Positronium Decay, T. Jamazaki et. al., PRL 104, 083401 (2010)

TABLE I. Summary of the systematic errors.

| Source | Systematic error |
|---|------------------|
| Table angle accuracy | ± 0.00039 |
| Center alignment | ± 0.00025 |
| Nonuniformity of aerogel/magnetic field | ± 0.00011 |
| Decrease of β^+ decay rate | ± 0.00030 |

$$C_{CP} = 0.0013 \pm 0.0021(\text{stat}) \pm 0.0006(\text{syst})$$

Set-up: repurpose of the ToF-PET model



Set-up: possible upgrade

- 24 BaF₂ crystals, 1-inch height, 1- or 2-inch diameter
- PMT Photonis XP2020/URQ, VD 127K/T and mu-metal shield MS172



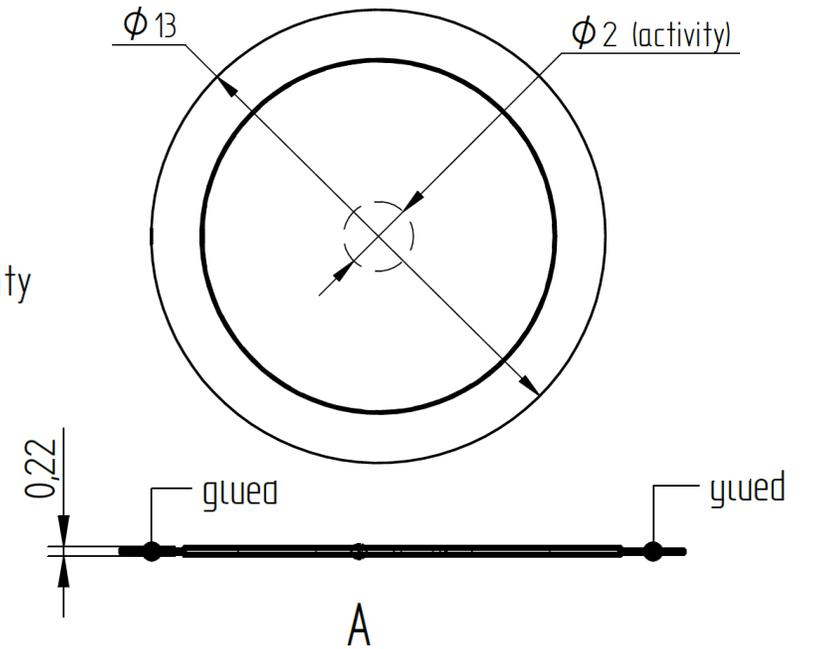
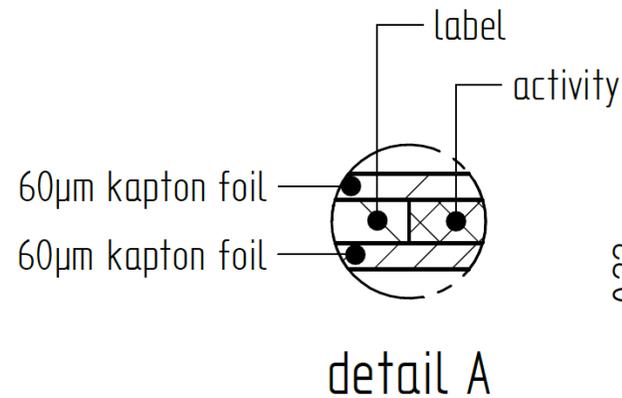
Set-up: Neodymium magnets and iron yoke

- Two 0.5 T Neodymium magnets having the height and the diameter of 4 cm
- The stand of the yoke has 4 screw for leveling and finer adjustments



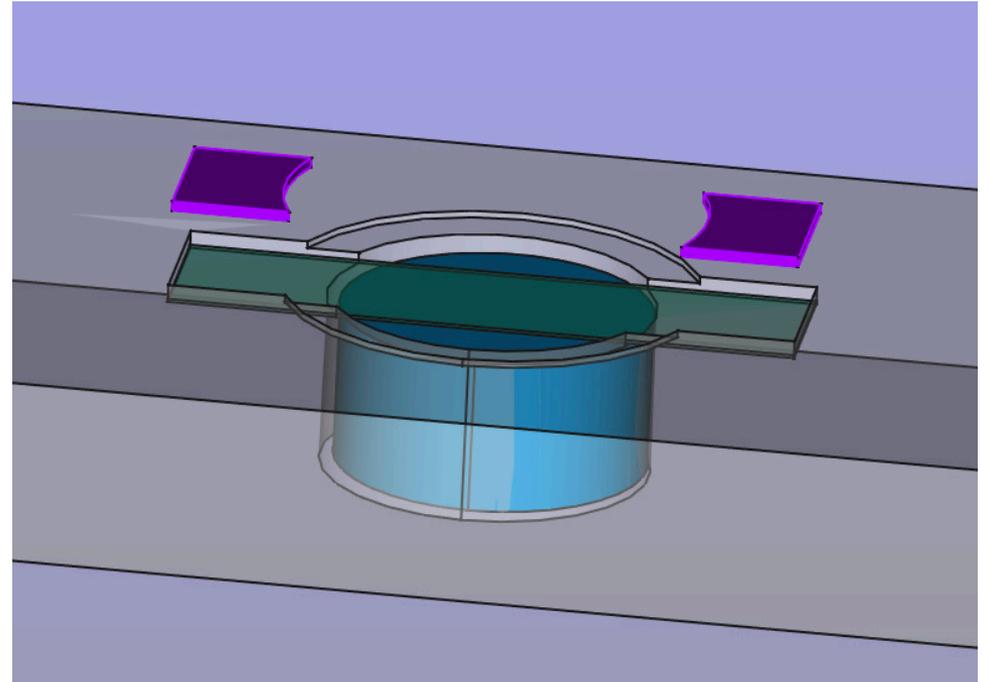
Set-up: ^{22}Na source and aerogel

- Two ^{22}Na sources 1 MBq and 3.7 MBq
- Aerogel cylinders 5 mm height and $\varnothing 10$ mm

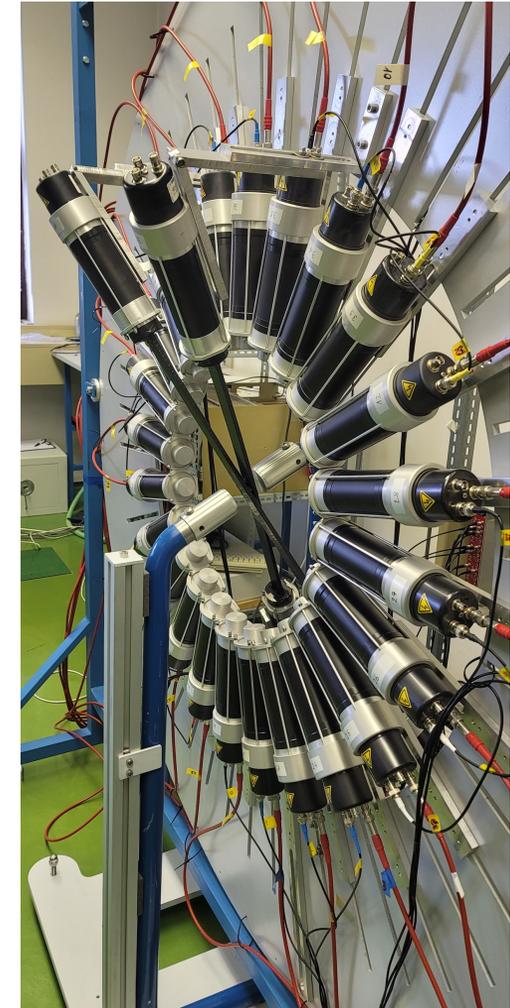
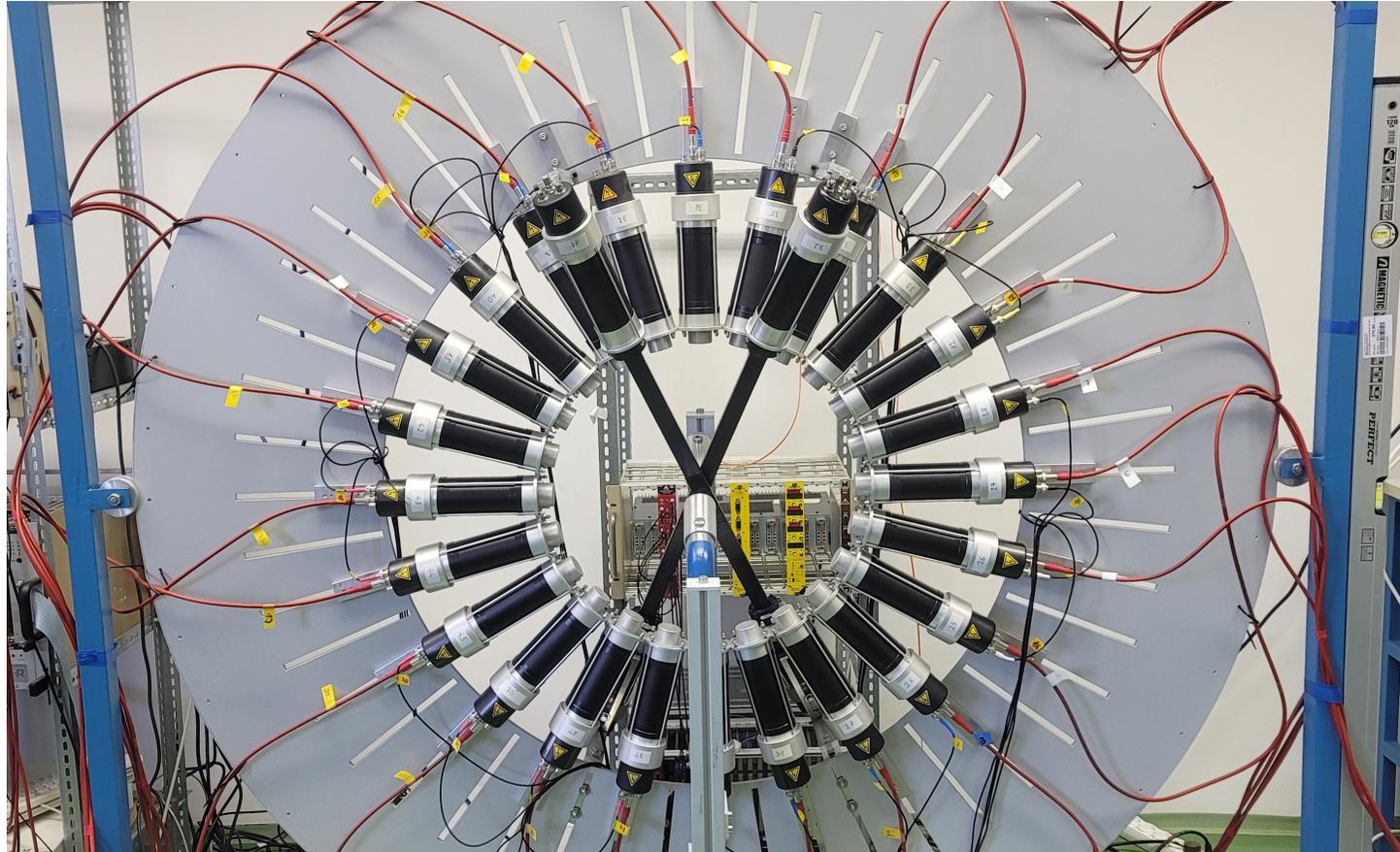


Set-up: Positron taggers

- EJ-212 Plastic scintillators 0.1-, 0.15- and 0.2-mm thickness
- Straight Plexiglass light guides --> Read-out on both sides
- Plexiglass scintillator covers



Set-up: Altogether

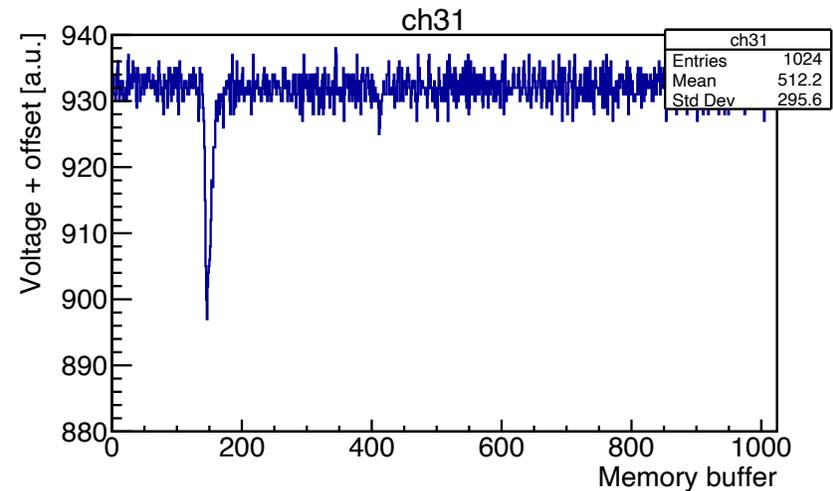
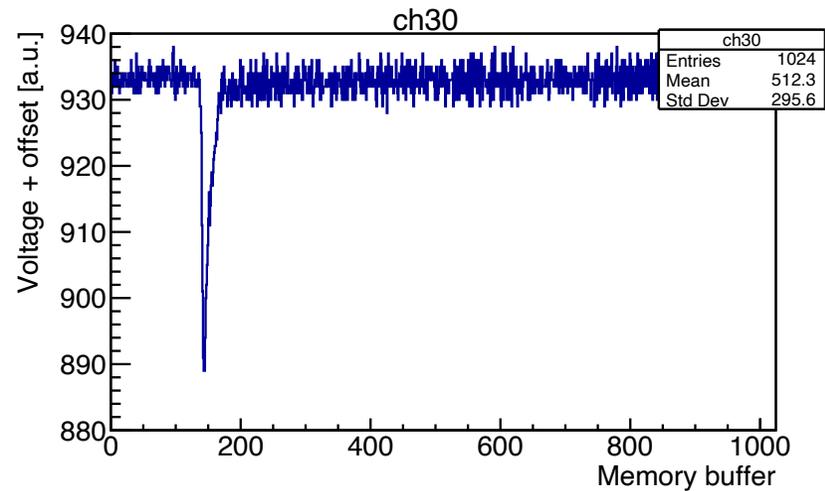
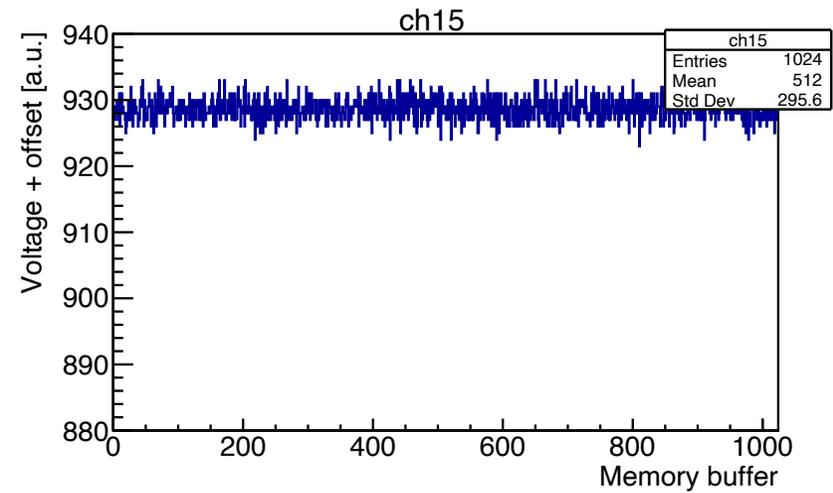
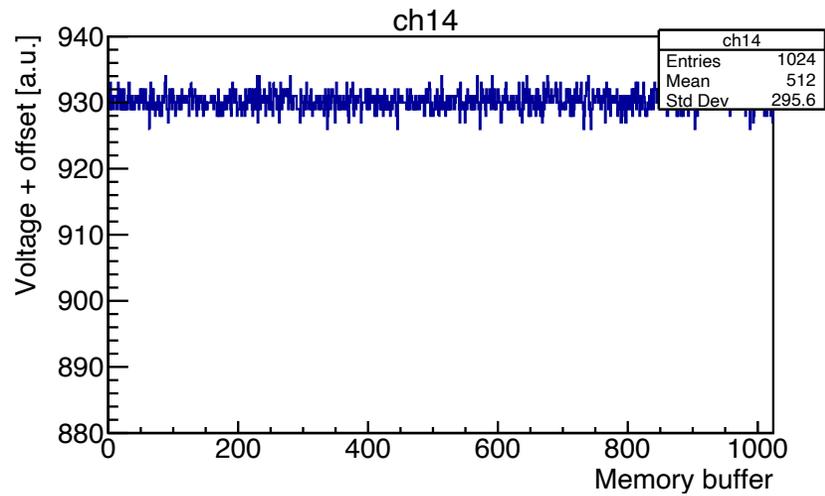


Data Acquisition System

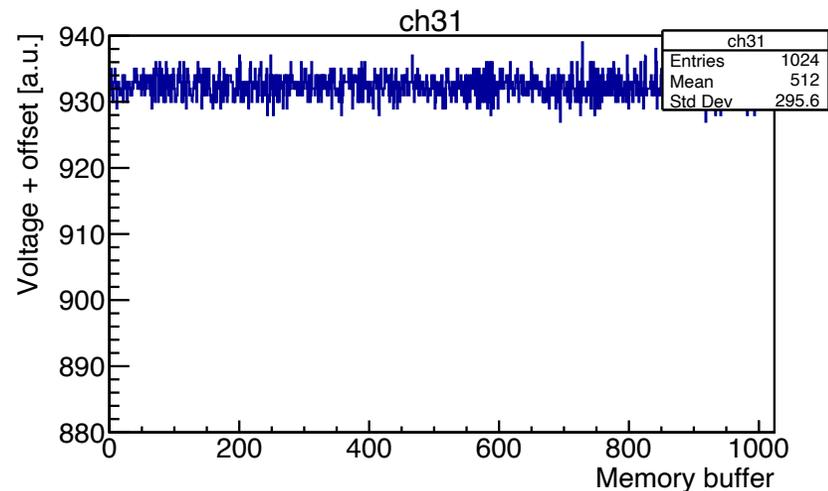
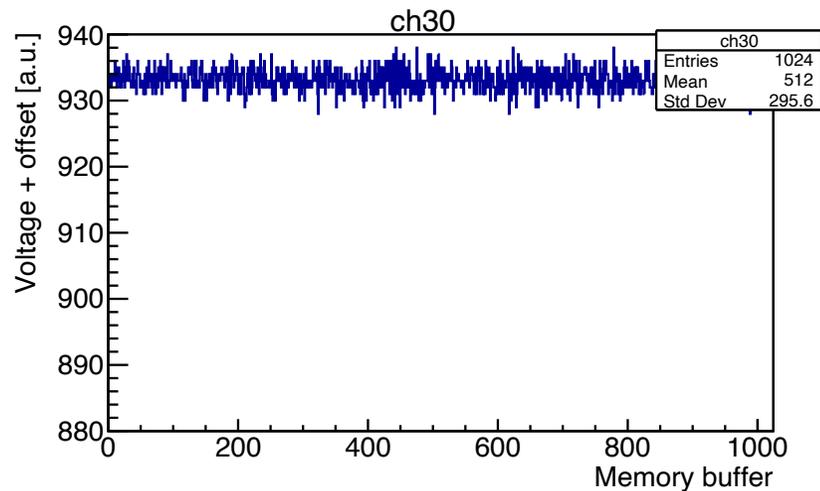
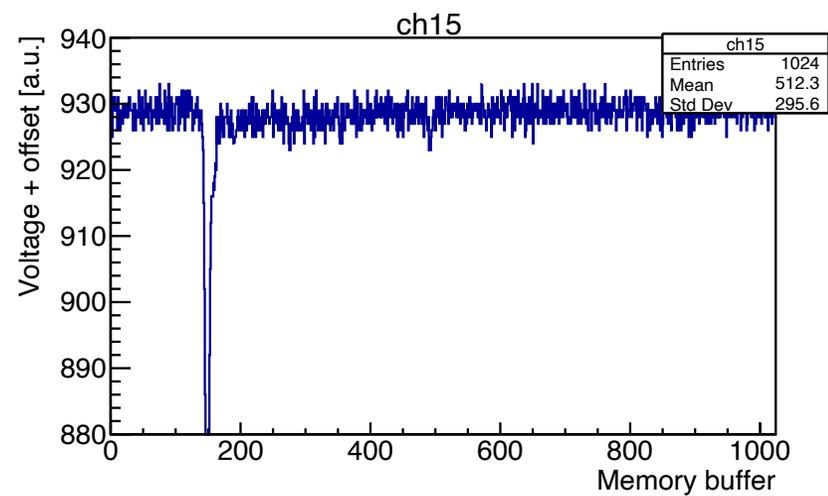
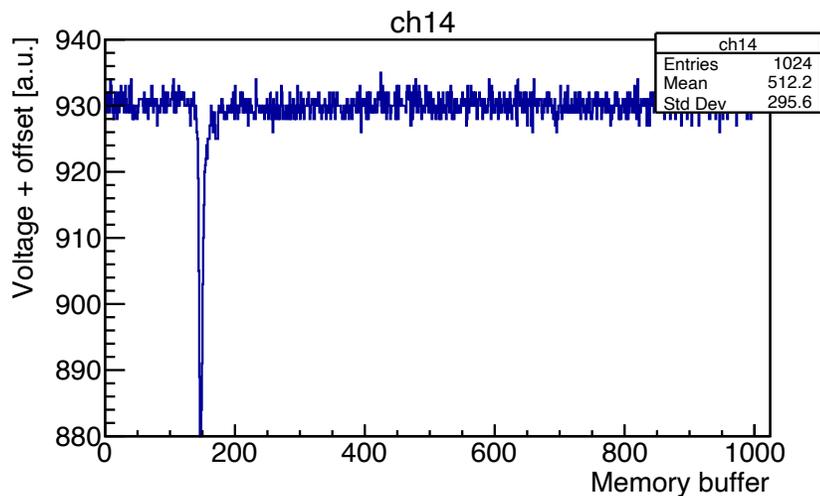
- 2x CAEN V1743 16-channel digitizers having 3.2, 1.6, 0.8 and 0.4 GS/s rates
- Digitizers are synchronized on common clock and common trigger logic
- Each digitizer reads 12 BaF₂ and two ends of one light guide
- Common trigger a) signals from both ends of the light guide in coincidence
b) majority signal



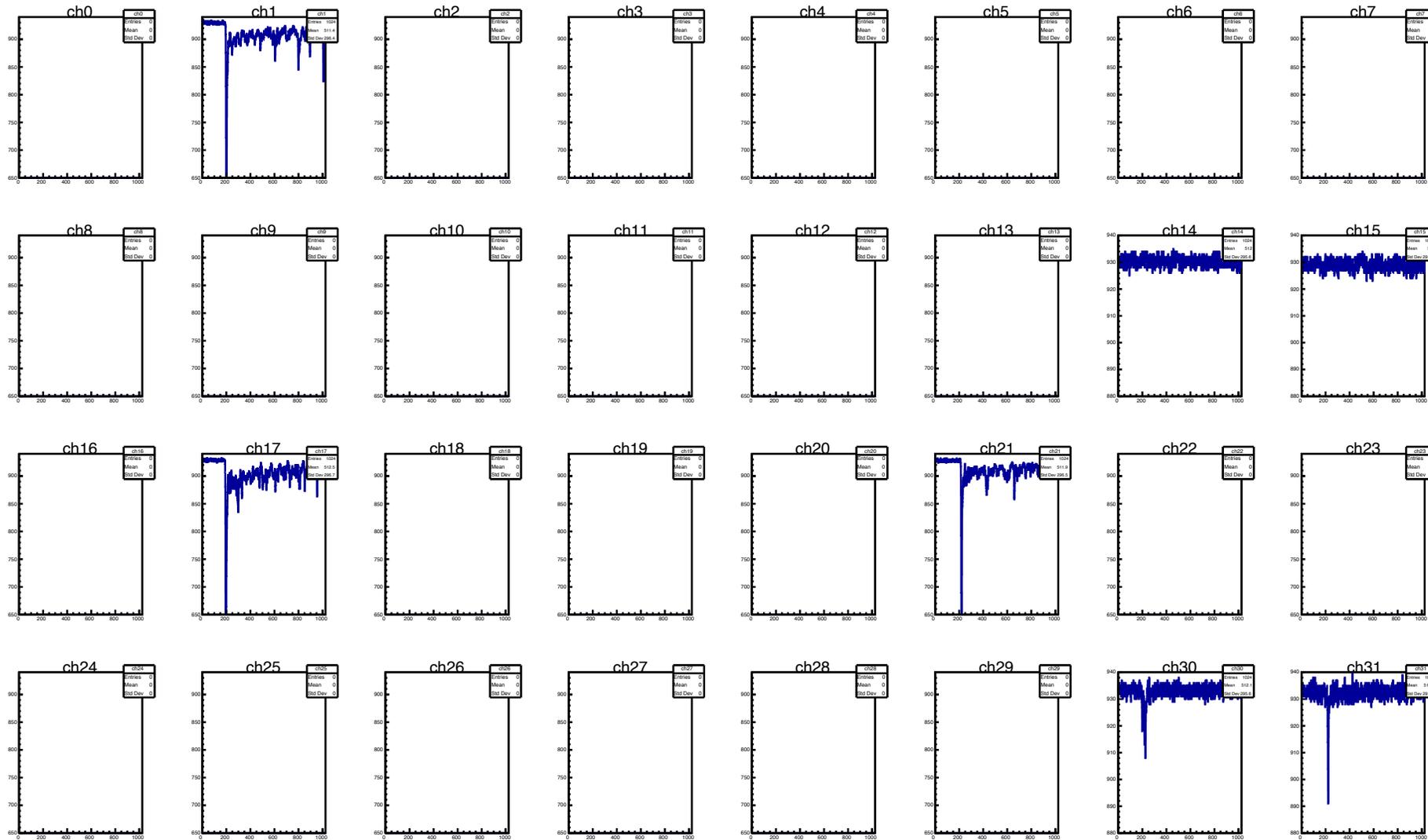
Recorded signals – thin scintillators



Recorded signals – thin scintillators

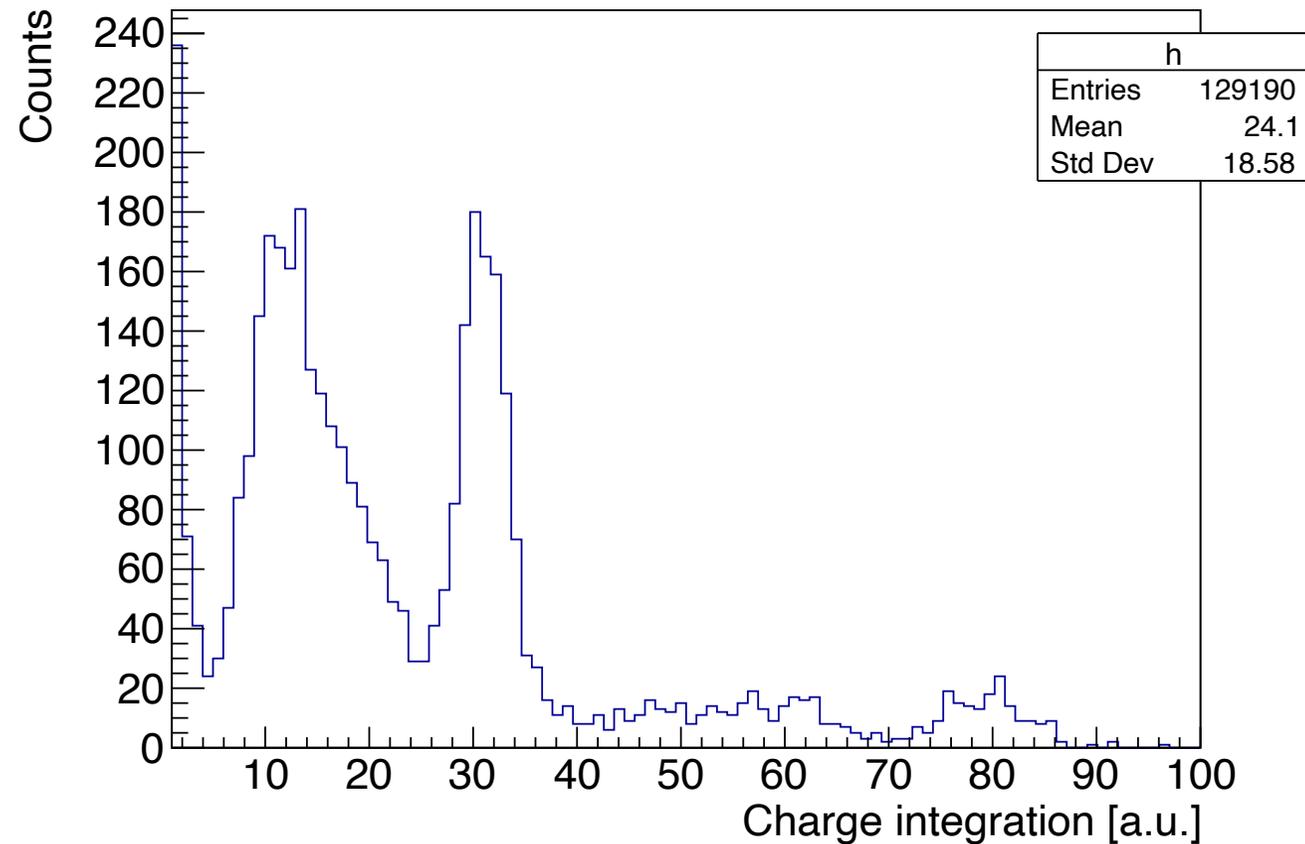


Recorded signals – majority trigger



Recorded signals

- Energy by simple charge integration -> 8.2 % relative sigma at 511 keV



Outlook

- Experimental set-up is completed
- We clearly see coincidence from thin positron tagging scintillators
- We see candidates for o-Ps events in test data runs
- At the moment waiting for two A1535 24-channel HV modules to return from repair

Thank you for your attention.

Search for CPT-Odd Decays of Positronium

J-PET tomograph, P. Moskal, et al. Nature Commun. 12, 5658 (2021).

$$A(\theta) = \frac{N(\theta) - N(-\theta)}{N(\theta) + N(-\theta)}$$

$$C_{\text{CPT}} = \langle O_{\text{CPT}} \rangle / P = 0.00067 \pm 0.00095.$$

P. A. Vetter and S. J. Freedman, PRL 91, 263401 (2003)

$$C_n = 0.0071 \pm 0.0062$$