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Interferometric techniques with high resolution emulsion detectors

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Project and its goal

- New interferometric technique
- Measurement of particle-antiparticle mass ratio
- Independent of particles' electric charges
- CPT violations and antimatter gravitational fall
- High-resolution detectors ⟶ Nuclear emulsions

Why nuclear emulsions?

- Position sensitive detectors
- Silver-bromide microcrystals
- Silver grains creation
- $\sim 1\ \mu m$ resolution
- Pattern with a period $\sim 7\ \mu m$ reconstructed [1]

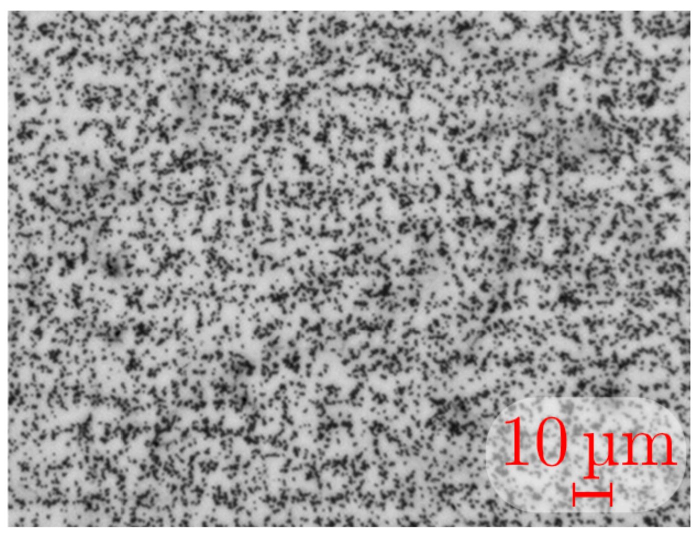

Figure 1: view of reconstructed grains in a nuclear emulsion after exposure

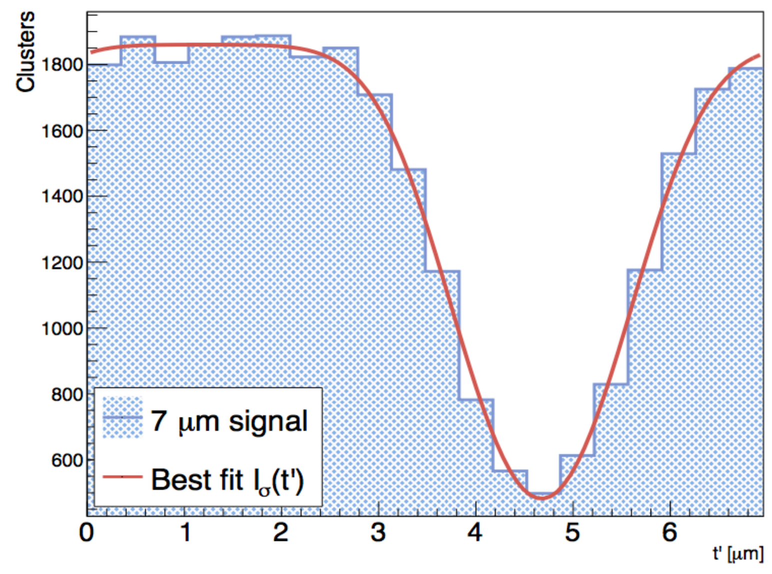

Figure 2: fit of the distribution of the grains after exposure

- Very high spatial resolution
- Recent development: super-fine-grained emulsions
- Up to $50\ nm$ resolution [2]
- Ideal device for quantum interferometry studies

QUPLAS apparatus

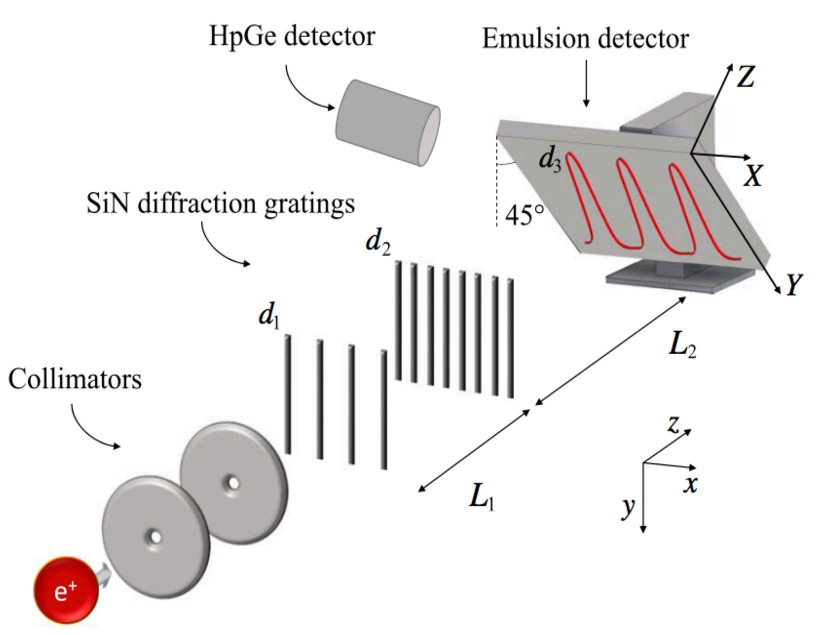

Figure 3: scheme of the QUPLAS apparatus

- Asymmetric Talbot-Lau interferometer [3]
- Continuous positron beam
- Diffraction gratings with different periods
- Emulsion detector
- $\sim 6\ \mu m$ interference fringes

Proposed configuration

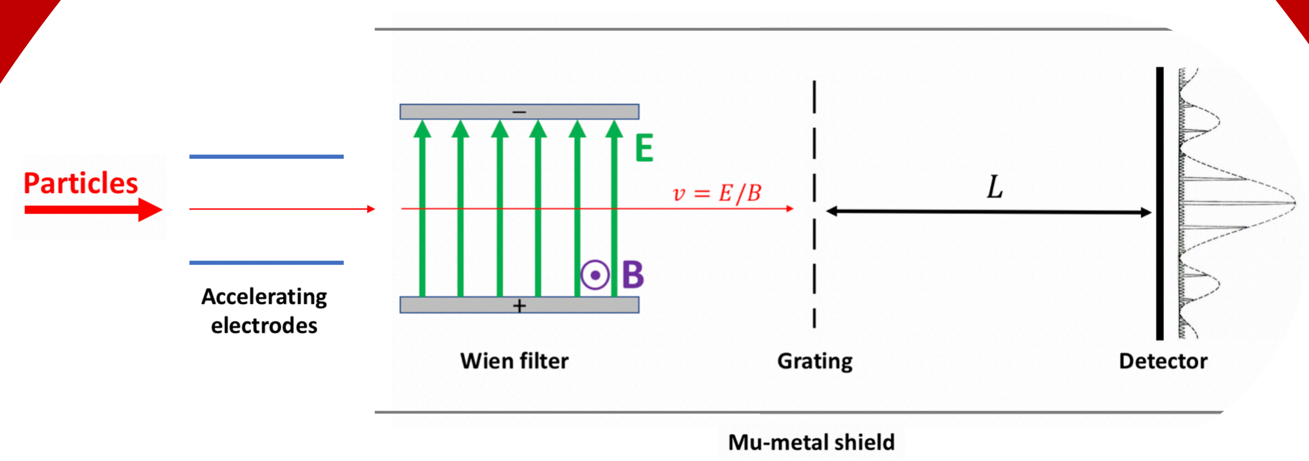

Figure 5: scheme of the proposed configuration for the measurement of the particle-antiparticle mass ratio [4]

- Accelerating electrodes
- Wien filter: orthogonal electric and magnetic fields
- Grating: Fraunhofer diffraction $L \gg \lambda$
- Emulsion detector: reconstruct diffraction pattern
- Cylindrical mu-metal shield

Particle-antiparticle mass ratio

- Inverting the De Broglie relation:

$$mc^2 = \frac{(hc/\lambda)^2 - K^2}{2K}$$

- $\lambda \rightarrow$ particle wavelength
- $K \rightarrow$ particle kinetic energy

- λ can be expressed as:

$$\frac{\lambda}{d} = \frac{|\Delta y|/L}{\sqrt{1+(|\Delta y|/L)^2}}$$

- $d \rightarrow$ grating period
- $|\Delta y| \rightarrow$ deviation from the centre of the screen
- $L \rightarrow$ distance between grating and screen

- Absolute mass of the particle:

$$mc^2 = \frac{hc}{d}\sqrt{\frac{c^2B^2}{E^2}-1}\sqrt{1+\left(\frac{L}{|\Delta y|}\right)^2}$$

- $E \rightarrow$ electric field
- $B \rightarrow$ magnetic field

- Particle-antiparticle mass ratio [4]:

$$\frac{m_2}{m_1} = \sqrt{\frac{1+(L/\Delta y_2)^2}{1+(L/\Delta y_1)^2}} \simeq \frac{|\Delta y_1|}{|\Delta y_2|}$$

- Same Wien filter (E, B)
- Same interference apparatus (L, d)
- $L \gg |\Delta y|$

QUPLAS results

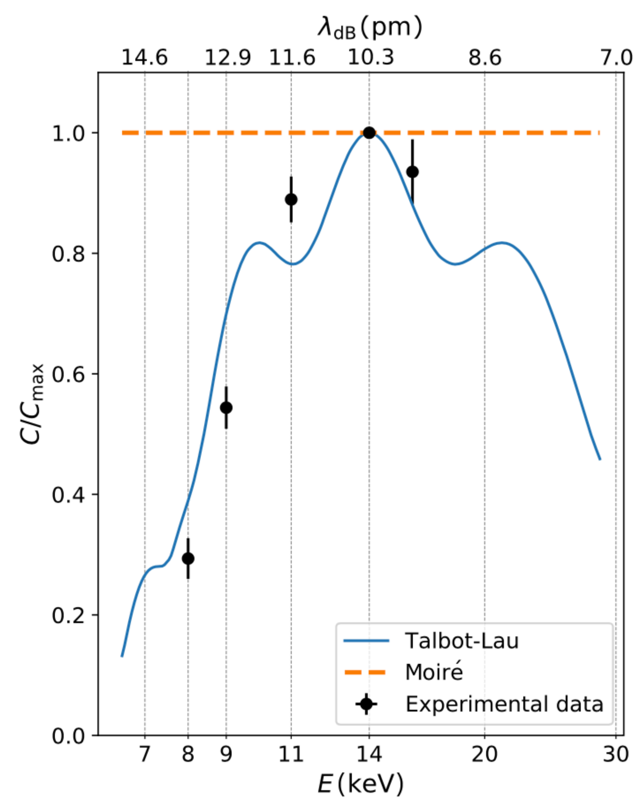

Figure 4: Contrast as a function of energy. Classical and quantum behaviour

- Different energies of the positron beam
- Contrast as a function of energy
- Quantum vs classical behaviour
- Detection of positron interference in the Talbot-Lau regime
- First demonstration of antimatter wave interferometry [3]

Conclusions

- Interferometric methods used to obtain a direct estimate of particle/antiparticle masses
- Method independent from particles' electric charges
- Particle-antiparticle mass ratio is independent from d, E, B
- Emulsion detectors critical for interferometric measurements

References

[1] S. Aghion et al. "Nuclear emulsions for the detection of micrometric-scale fringe patterns: an application to positron interferometry". *Journal of Instrumentation* 13.05 (2018)

[2] A. Alexandrov et al; Sci. Rep. 2020, 10, 18773

[3] S. Sala et al. "First demonstration of antimatter wave interferometry." *Science advances* 5.5 (2019): eaav7610

[4] E. Pasino et al. "An Interferometric Method for Particle Mass Measurements." *Symmetry* 13.7 (2021): 1232