Antimatter gravity and interferometry

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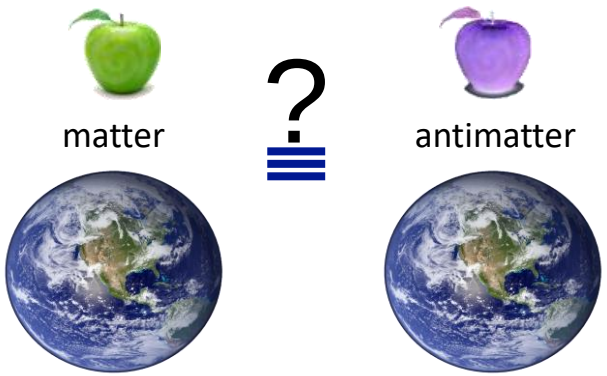
with contribution from Paolo Crivelli (ETH) and Anna Soter (PSI)

SWICH Strategy Workshop
3-6 April, SBB Centre Löwenberg, Murten

Gravitational interaction between matter and antimatter

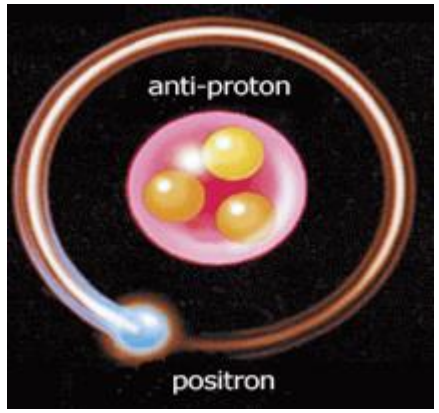


Experiments aimed at testing the Week Equivalence Principle

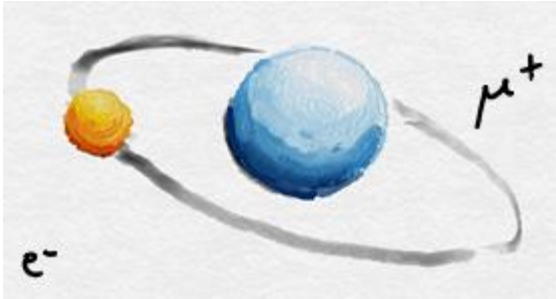
Universality of Free-Fall (UFF) tested to 1 part in 10^{12}, but only with matter based experiments.

- Indirect limits $\bar{g}/g-1 < 10^{-7}$
- Direct limit: $-65 < \bar{g}/g < 110$ (ALPHA, Nat. Comm. 4, 1785, 2013)

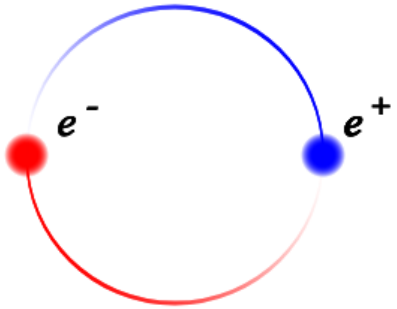
Antimatter gravity experiments with swiss participation



Antihydrogen at the CERN AD/ELENA:
GBAR experiment
Swiss institution involved: ETHZ



Muonium at Paul Scherrer Institute
Swiss institutions involved: ETHZ, PSI



Positronium at L-NESS (Como, Italy)
QUPLAS experiment
Swiss institutions involved: Uni Bern

Gravitational Behavior of Anti-Hydrogen at Rest

17 Institutes, 70 scientists
Swiss involvement (ETHZ): 6 scientists

Goal: Perform a measurement of the effect of gravity on anti-hydrogen at the 1% level in a 1st phase (free fall) and at the 10^{-5} or better in a 2nd phase (quantum gravitational states)

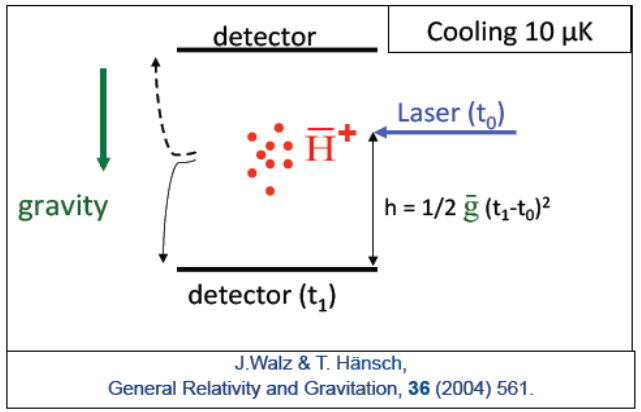
Idea: to minimize initial velocity (main systematic)

1) Produce anti-hydrogen ions H^+ using :

$$1)\ \mathrm{Ps} + \bar{\mathrm{p}} \rightarrow \bar{\mathrm{H}} + \mathrm{e}^-$$

$$2)\ \mathrm{Ps} + \bar{\mathrm{H}} \rightarrow \bar{\mathrm{H}}^+ + \mathrm{e}^-$$

2) Sympathetic cooling of $Hbar^+$ with Be^+ → 10 μK
3) Photodetachment of e^+ → ultra cold neutral Hbar
4) Measurement of the time-of-flight



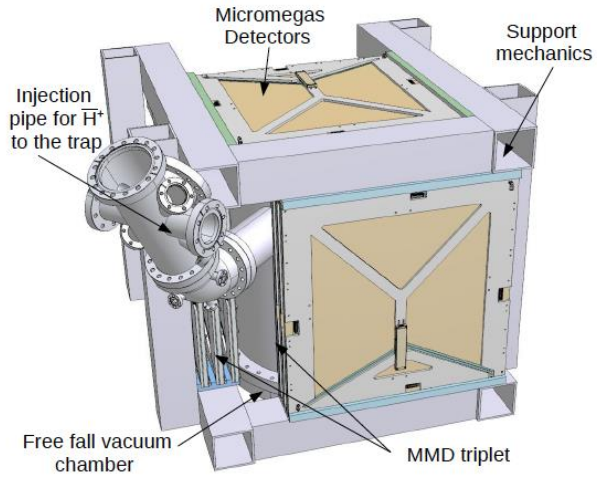
Status: experiment currently under installation and commissioning.

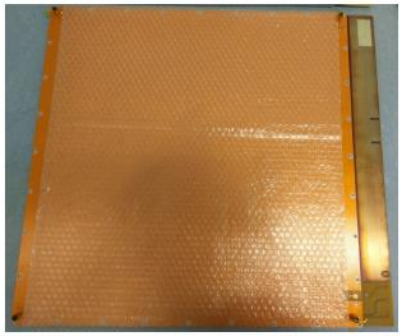
1) Anti-proton decelerator connected to ELENA
2) Slow positron beam from LINAC produced
3) Buffer gas trap and positronium chamber being commissioned

BEAM TIME STARTING IN AUGUST 2018
GOAL: attempt anti-hydrogen production

Responsibility of Swiss participants in GBAR (ETHZ): GBAR tracker

Funding: SNSF FLARE 173597





Full detector: 6 triplets of 50 x 50 cm^2 multiplexed Micromegas detectors

Status: triplet prototype 50x50cm^2 installed in GBAR zone.

Outlook: Full detector should be ready for after LS2 for the free fall measurement

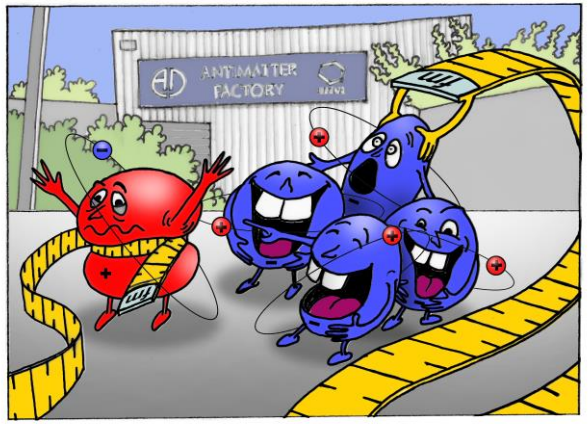
Measurement of the Lamb shift in GBAR

Funding: ETHZ grant ETH-46 17-1

Goal: sensitive test of CPT and Lorentz symmetries (complementary to 1S-2S and HFS transitions) and 1st determination of pbar charge radius.

Idea: charge exchange reaction produces HBAR(2S). Induce 2S→2P transition with MW. Detect depleted H(2S).

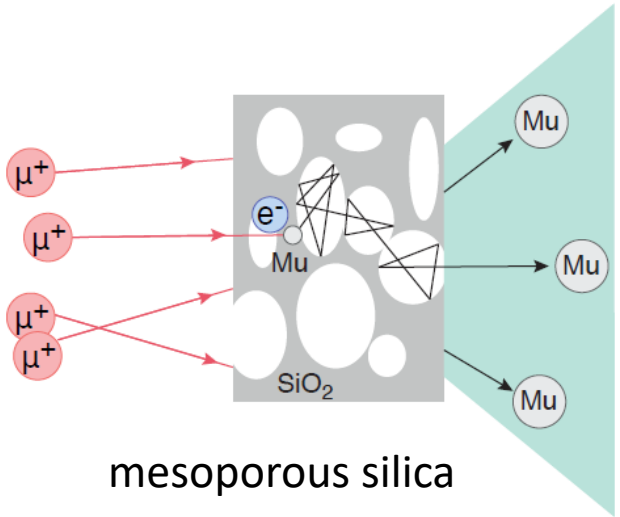
Status&Outlook: Lyman alpha detector being assembled. Tests with H June-August. First attempts to detected HBAR 2S→2P in 2018.
Measurement at 100 ppm after LS2



P. Crivelli, D. Cooke, M. Heiss, Phys. Rev. D 94, 052008 (2016), editor suggestion

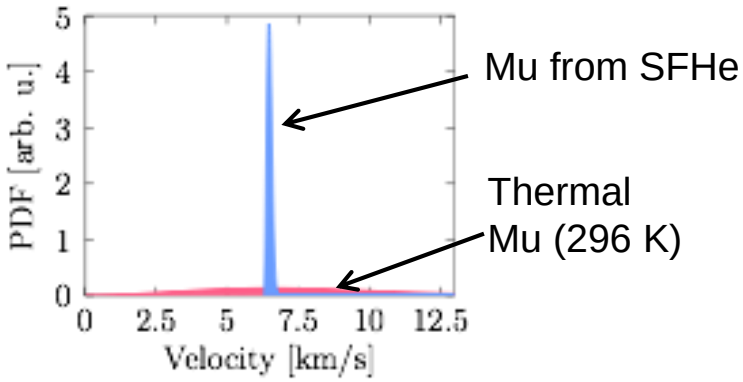
Proposal: Mu production in superfluid helium (SFHe)

State-of-the-art Mu creation

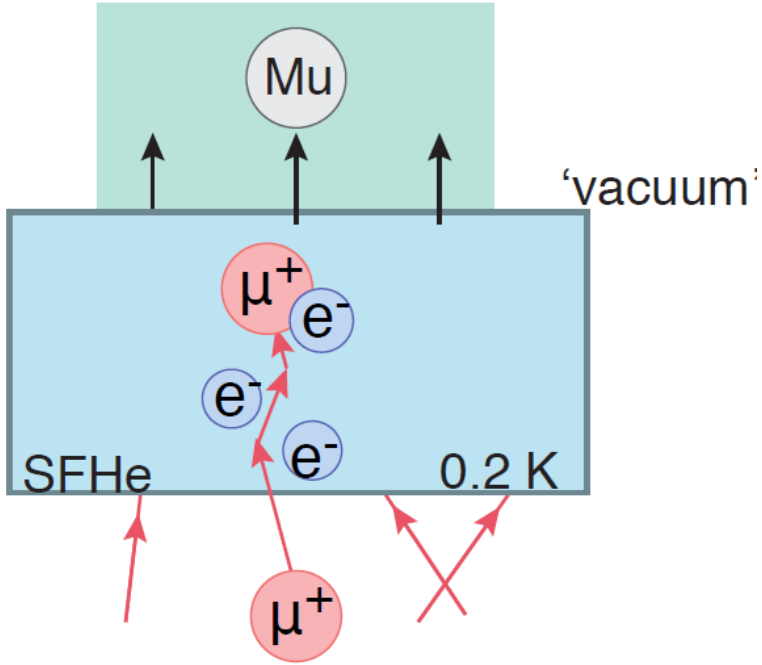


mesoporous silica

- Large (thermal) energy spread
- Broad angular distribution (~cosθ)



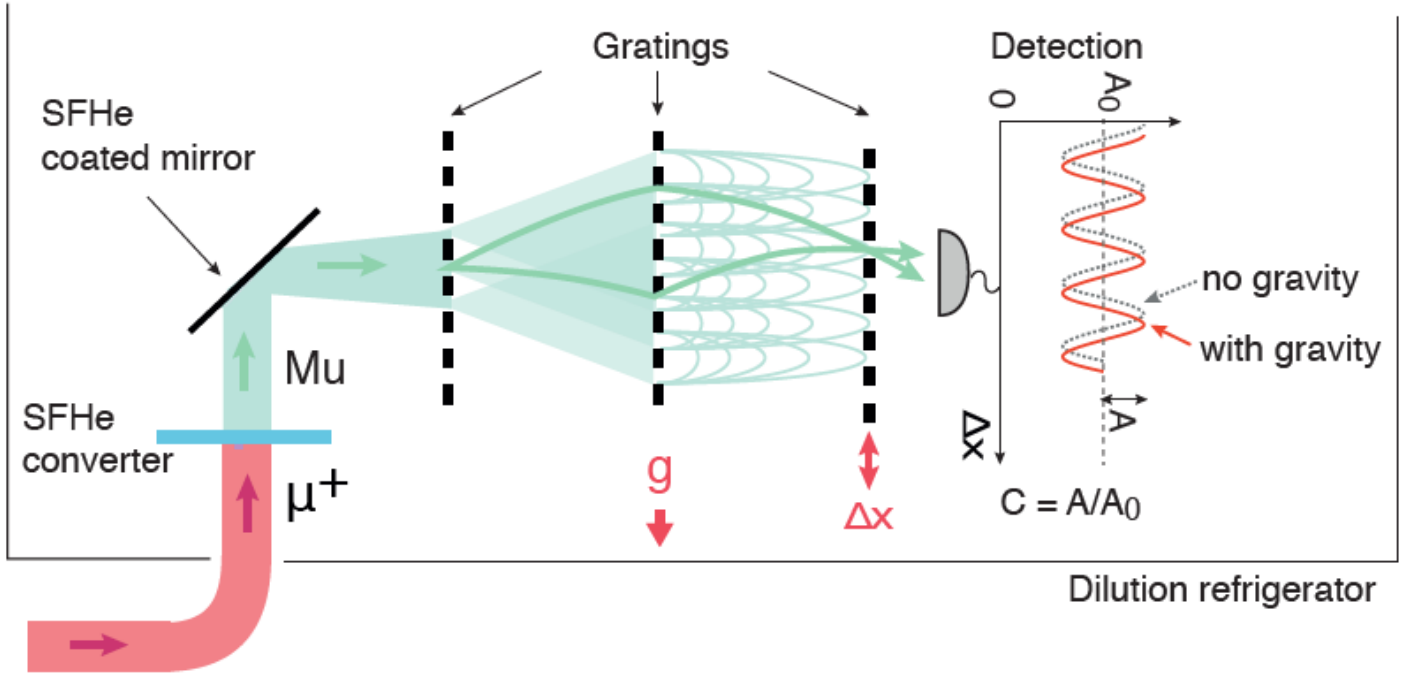
High quality Mu beam from SFHe



- Mu ejected from SFHe surface with work function ~270 K (v = 6 mm/μs)
- Low (thermal) energy spread: ~0.07 %
- Narrow angular distribution: ~30 mrad

D. Taqqu, *Physics Procedia* 17, 216 (2011)

A possible Mu gravity experiment using SFHe converters

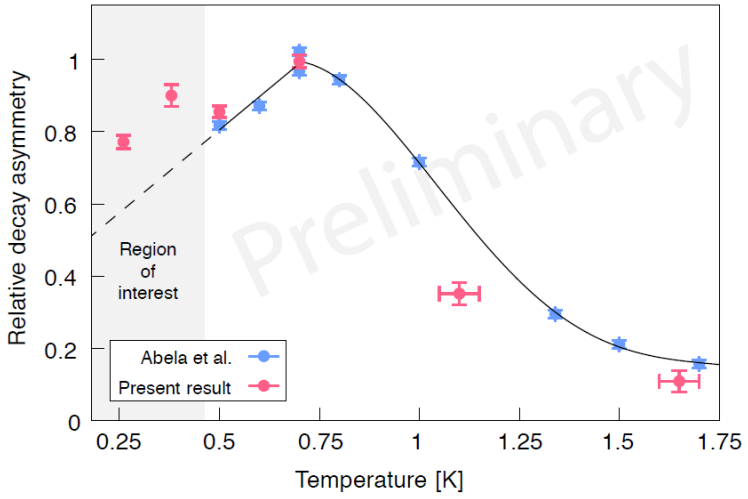


- Interaction time limited to few μs (τ_{Mu} ~2.2 μs) ➛ less than 1 nm gravitational deflection, implying small (~ 100 nm) necessary grating periods
- The expected Mu velocities (~ 6 mm / μs) would put the setup into the far field interferometry regime ➛ spatial coherence properties of the beam are vital!

Strategy:
- realizing the new Mu beam
- if high spatial coherence achieved ➛ gravitational interferometry
- lower coherence beam still would improve spectroscopy result of Mu

Status: large Mu production rates in T ~0.26 K bulk SFHe

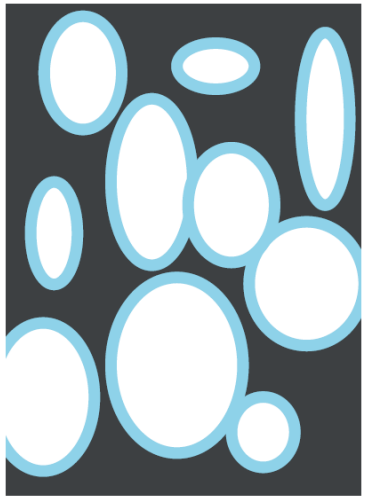
Abela et al. JETP Letters 57, 157 (1993)

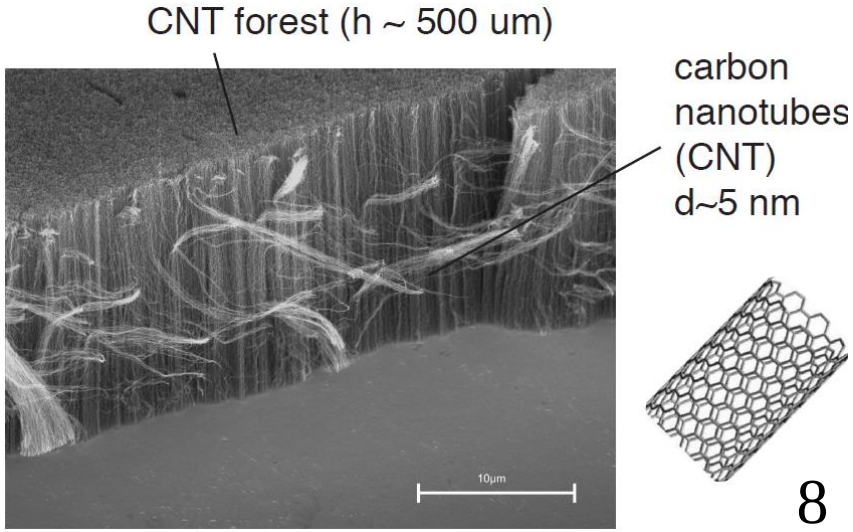


μ Spin Resonance measurements:
Temperature dependence of Mu production efficiency:
high (>70%) production rates were found at T=0.26 K

Plans for 2018: extraction of Mu from SFHe to vacuum

Instead of a flat SFHe surface and extensive μ^+ beam modification (vertical bending), we first use conventional beams and coat porous targets with superfluid helium

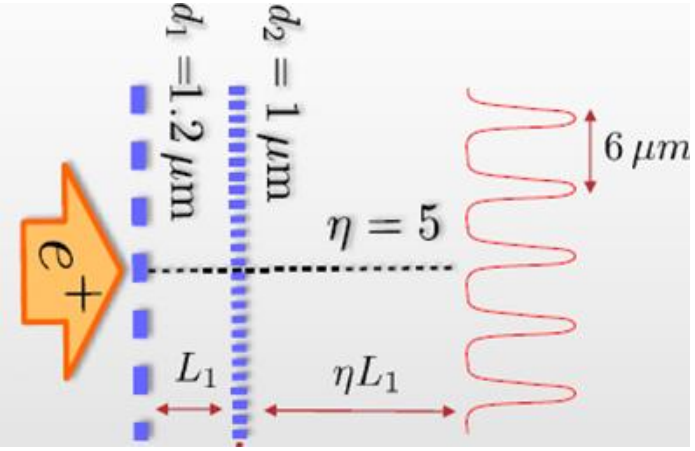




The QUPLAS experiment

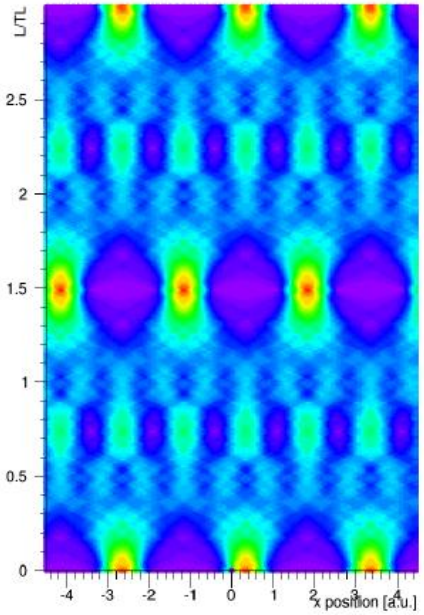
QUantum interferometry and gravitation with Positrons and LASers

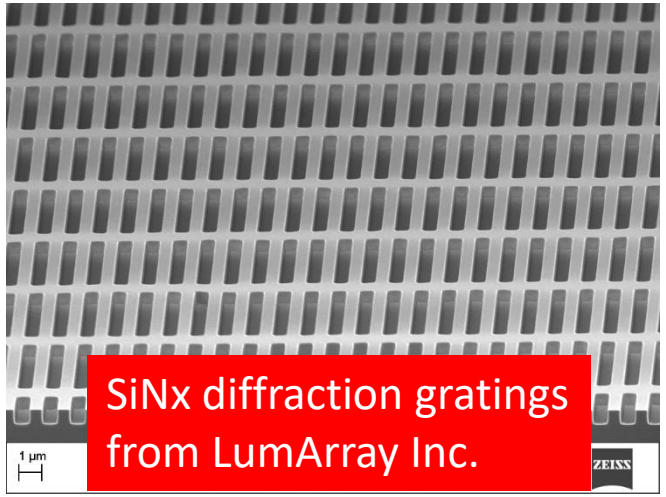
- Matter wave interference
- Positronium and WEP testing



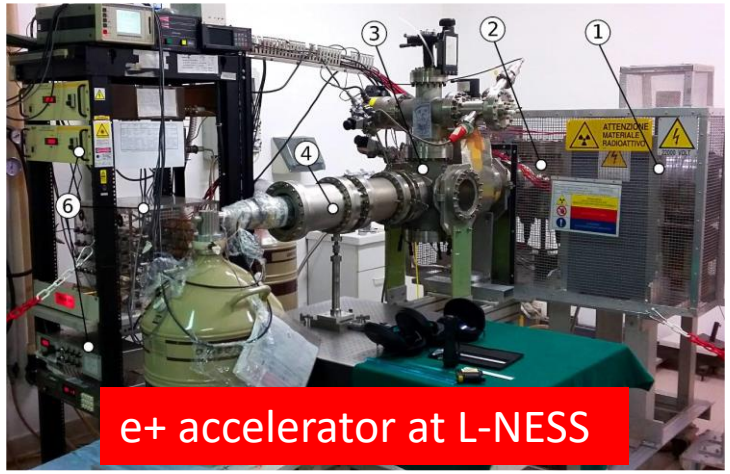
Interferometry with positrons: Asymmetric Talbot-Lau interferometer to provide fringe period magnification

S. Sala et al., Phys. Rev. A94 (2016) 33625
S. Sala et al., J. Phys. B48 (2015) 195002

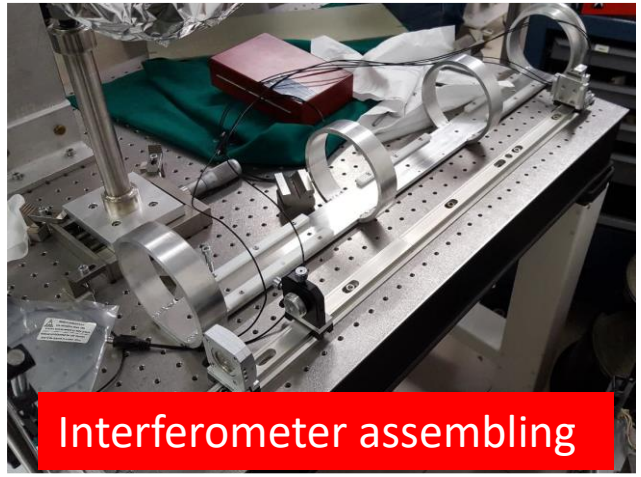




SiNx diffraction gratings from LumArray Inc.

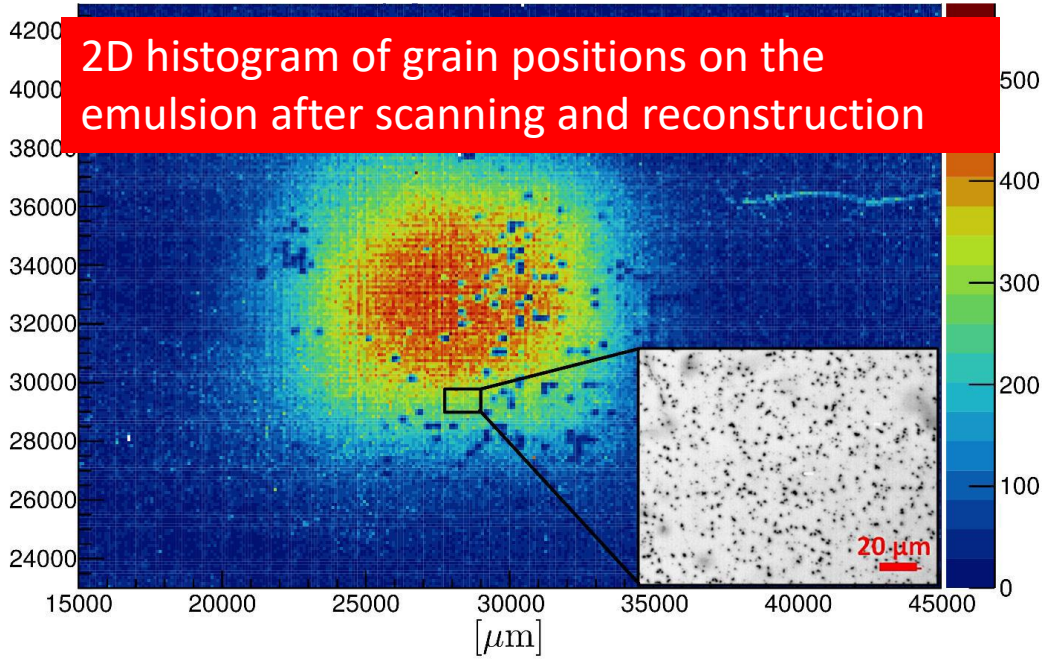


e+ accelerator at L-NESS

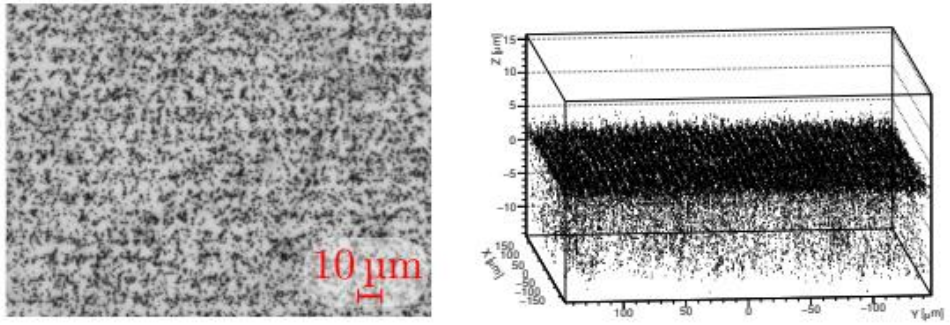


Interferometer assembling

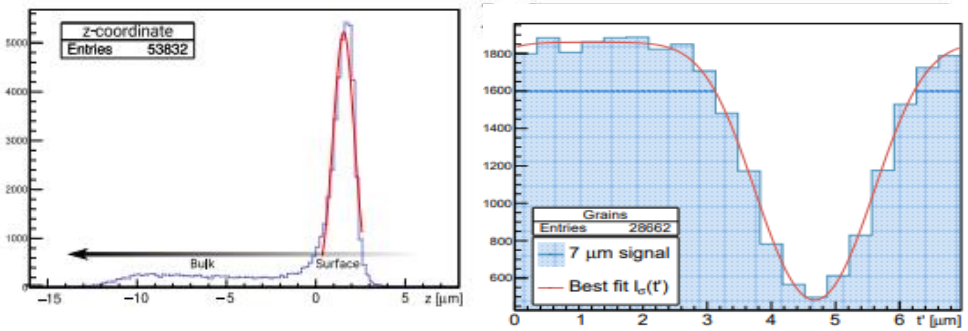
Responsibility of Swiss participants in QUPLAS (Bern): emulsion e+/Ps detector



Detectability of 10 keV e+ proven
S. Aghion et al., JINST 11 (2016) P06017



Detectability of few µm fringes proven
(emulsions directly in contact with gratings)
S. Aghion et al, arXiv:1802.04074



Status: the interferometer is ready, alignment tests ongoing, pilot exposure this week
Goal (dream?): first observation of antimatter waves interferometry before summer

Conclusions

Several swiss groups involved into antimatter gravity experiments

GBAR is the first experiment to receive antiprotons from ELENA. Commissioning ongoing. Hope to produce antihydrogen this summer before LS.

Other ideas involving fully leptonic atoms are being developed

Important *side* measurements (interferometry, spectroscopy) ongoing

Looking forward to delivering *large impact* results