Tailoring mechanical properties of optomechanical detectors

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Outline

INTRODUCTION

LAYMAN'S VIEW

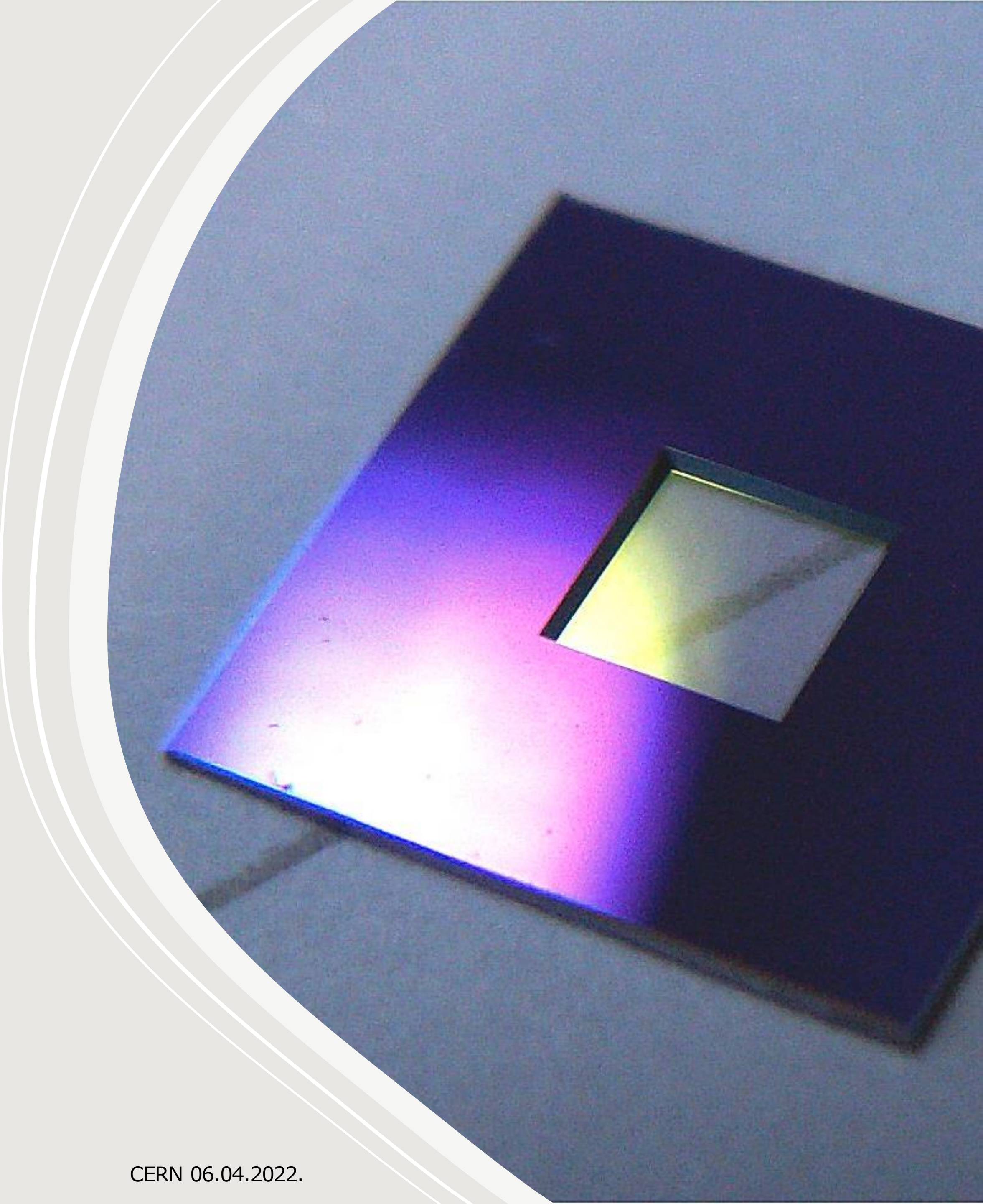
CONCLUSION AND OUTLOOK

Introduction

QUANTUM-LIMITED SENSORS, I.E., WORKING AT THE SENSITIVITY LIMITS IMPOSED BY HEISENBERG UNCERTAINTY PRINCIPLE

EXPLORING THE BOUNDARY BETWEEN THE CLASSICAL MACROSCOPIC WORLD AND THE QUANTUM MICROWORLD

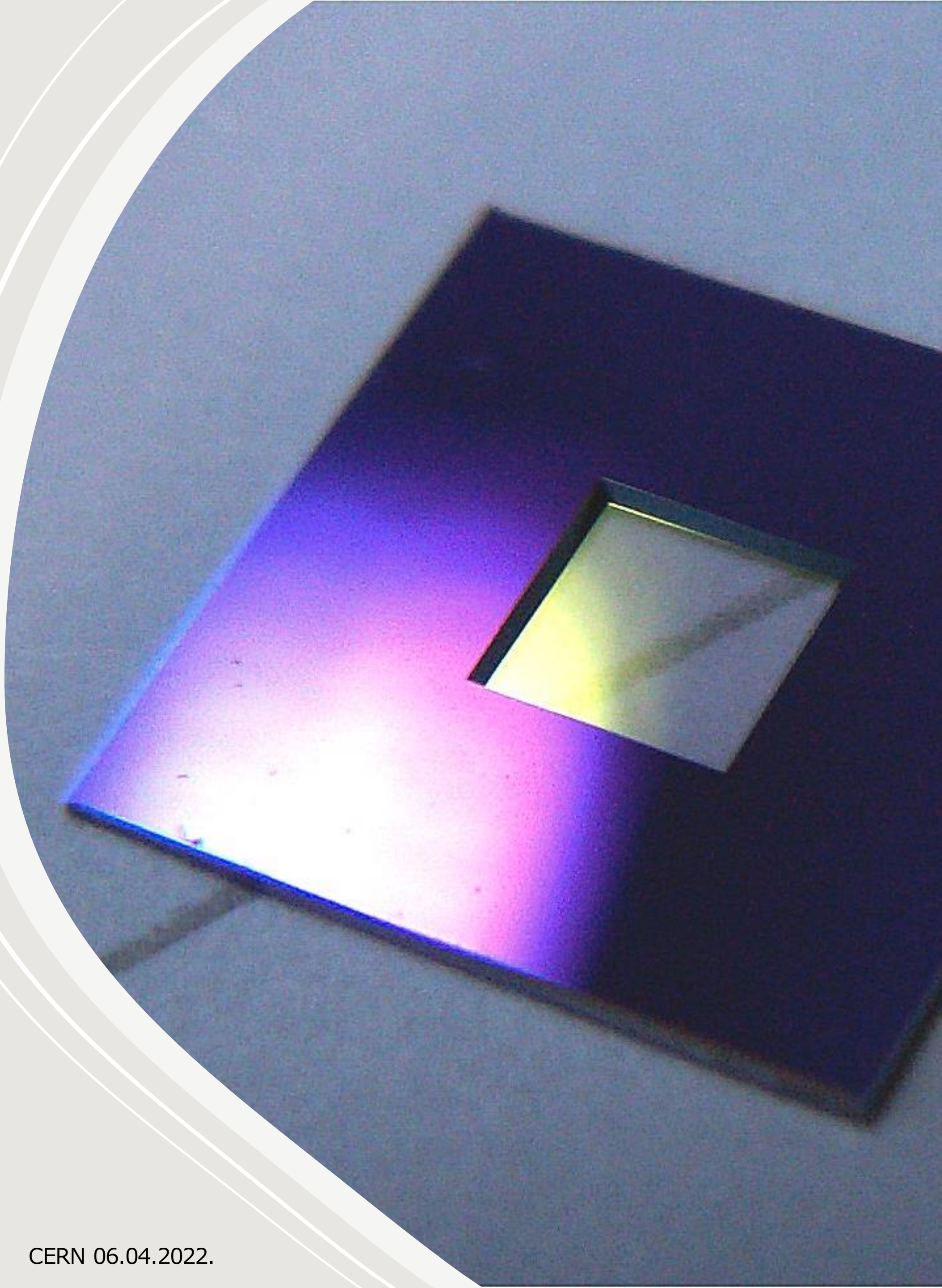
QUANTUM INFORMATION APPLICATIONS (OPTOMECHANICAL AND ELECTROMECHANICAL DEVICES AS LIGHT-MATTER INTERFACES AND QUANTUM MEMORIES)



Start from scratch …

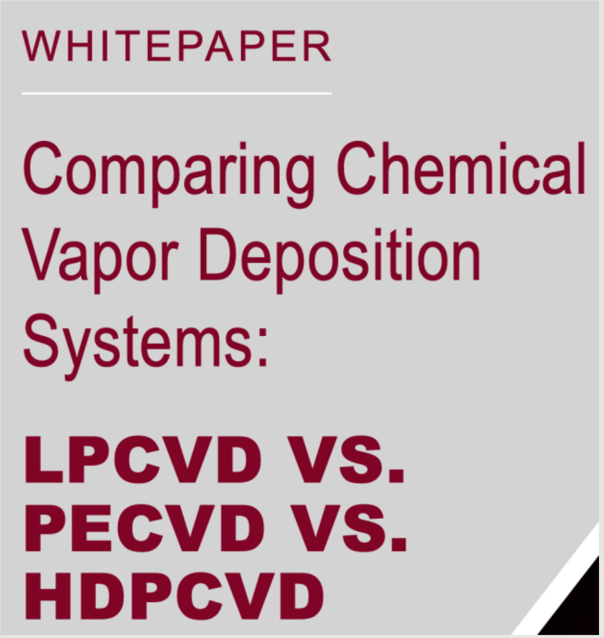
- silicon wafer (200um)
- PECVD --> SiNx
- etching --> window
- low stress --> low mechanical frequency

$$f = \frac{\sqrt{2}}{2L}\sqrt{\frac{T}{\rho t}}$$



Start from scratch ...

D. G: Lishan, K.D. Mackenzie



WHITEPAPER

Comparing Chemical Vapor Deposition Systems:

LPCVD VS. PECVD VS. HDPCVD

- during deposition

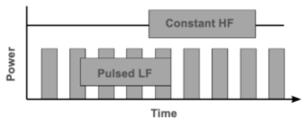


Figure 6: Pulsed low frequency super-imposed on constant high frequency power.

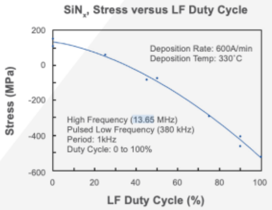
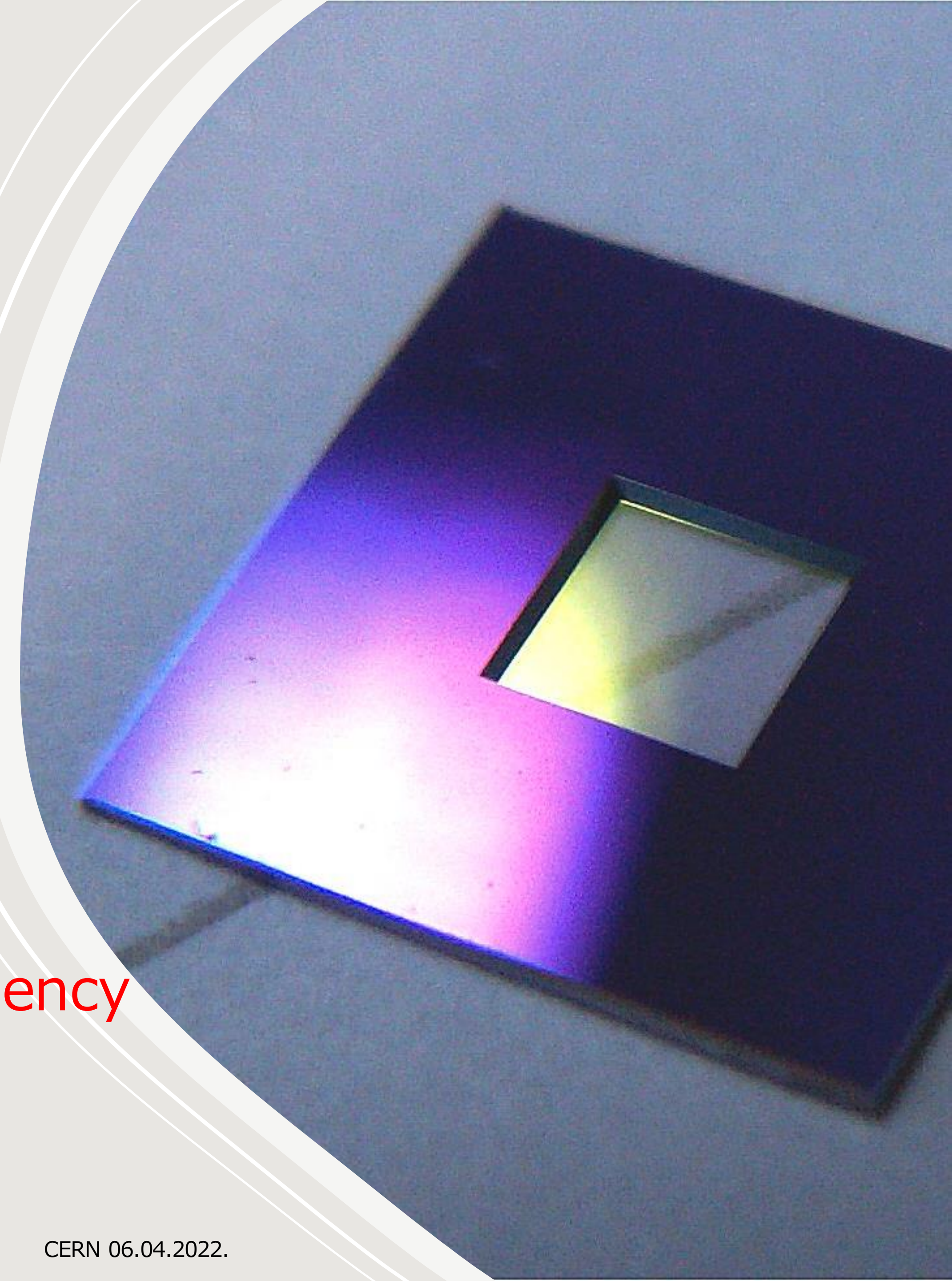


Figure 7: Example of PECVD SiN$_x$ stress control with addition of low frequency pulsing.

- after deposition
- thermal annealing (600 °C)

high stress --> high frequency



Start from scratch ...

HIGH-Q SI3N4 MEMBRANE WINDOWS

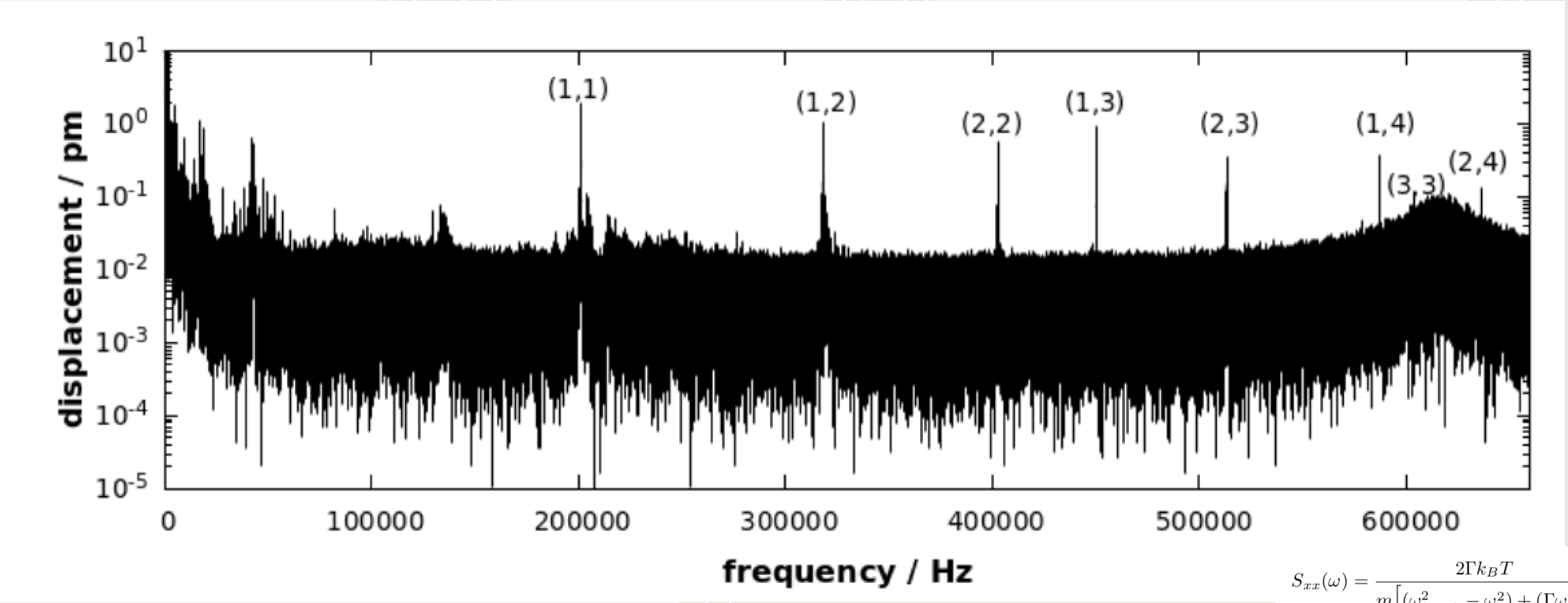
Norcada's Nitride Windows individually packaged in gel capsules for ease of handling.

Norcada's Nitride Windows are carefully cleaned to minimize contamination.

$$m\ddot{x} + D\dot{x} + kx = F\ \sin(\omega t)$$

$$f = \frac{\sqrt{2}}{2L}\sqrt{\frac{T}{\rho t}}$$

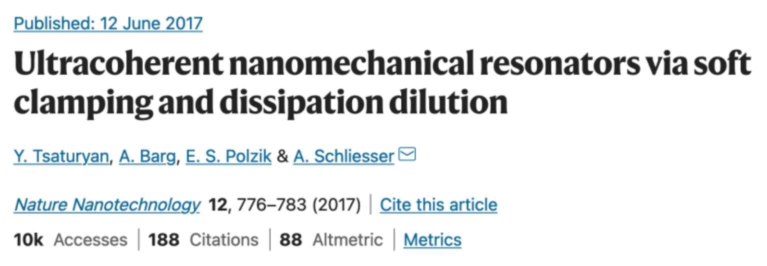
$$\omega_{mn} = \pi v\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$



$$S_{xx}(\omega) = \frac{2\Gamma k_B T}{m\left[(\omega^2_{(n,m)} - \omega^2) + (\Gamma\omega)^2\right]}$$

- oscillator thermally excited (F – white noise)

Start from scratch ...



Published: 12 June 2017

Ultracoherent nanomechanical resonators via soft clamping and dissipation dilution

Y. Tsaturyan, A. Barg, E. S. Polzik & A. Schliesser

Nature Nanotechnology **12**, 776–783 (2017) | Cite this article

10k Accesses | **188** Citations | **88** Altmetric | Metrics

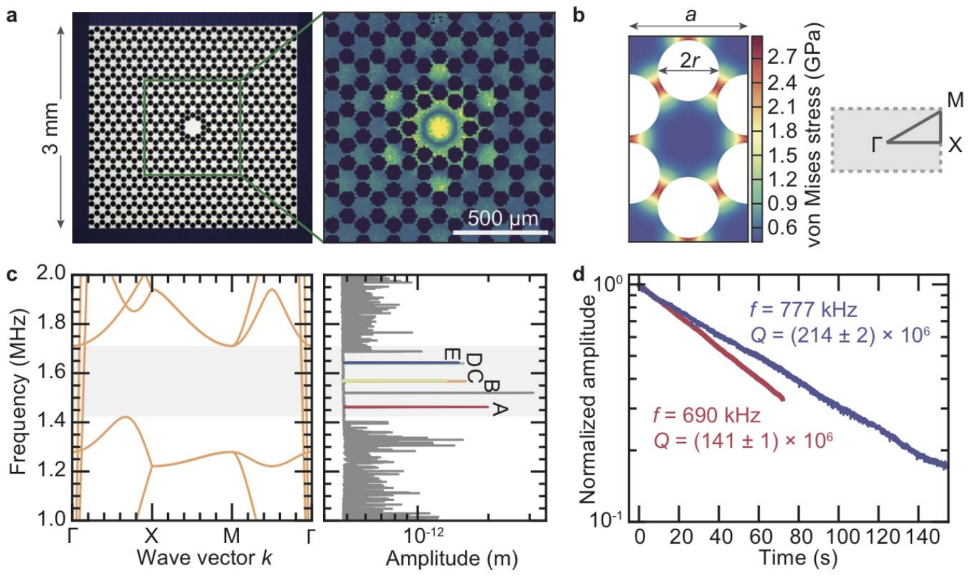
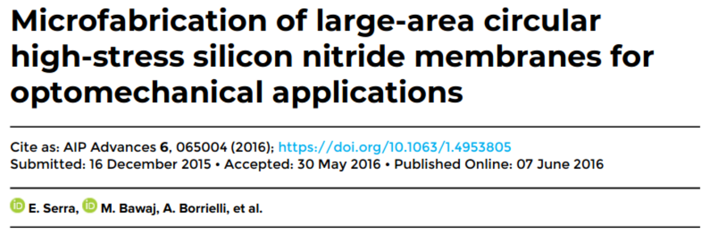


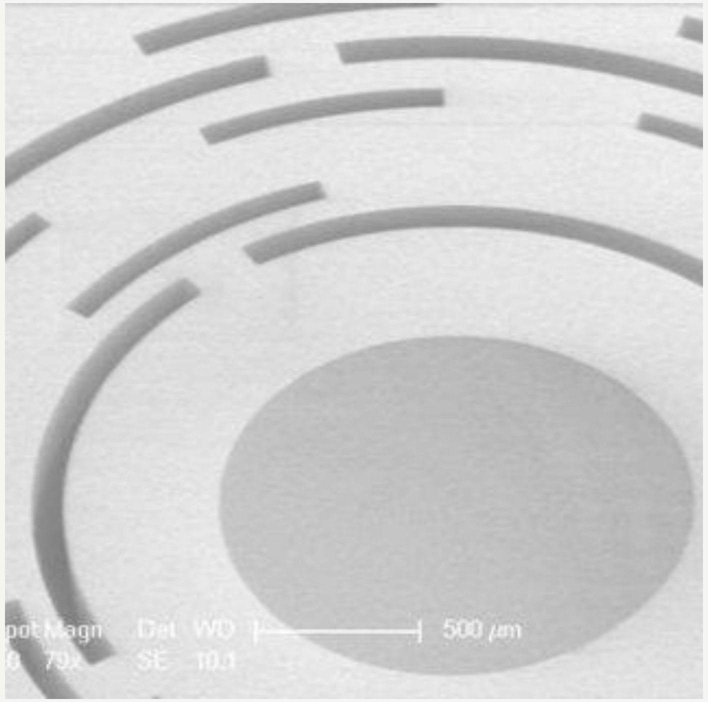
FIG. 1: **Device characterisation** **a)** Micrograph of a silicon nitride membrane patterned with a phononic crystal structure (left) and measured out-of-plane displacement pattern of the first localized mode "*A*" (right), of a device with lattice constant $a = 160\mu$m. **b)** Simulation of the stress redistribution in a unit cell of the hexagonal honeycomb lattice (left) and the corresponding first Brillouin zone (right). **c)** Simulated band diagram of a unit cell (left) and measured Brownian motion in the central part of the device shown in (a). Localized modes *A*-*E* are colour-coded, the peak around 1.5 MHz is an injected tone for calibration of the displacement amplitude. **d)** Ringdown measurements of *A* (red) and *E* (blue) modes of two membrane resonators with $a = 346\mu$m.



Microfabrication of large-area circular high-stress silicon nitride membranes for optomechanical applications

Cite as: AIP Advances **6**, 065004 (2016); https://doi.org/10.1063/1.4953805
Submitted: 16 December 2015 • Accepted: 30 May 2016 • Published Online: 07 June 2016

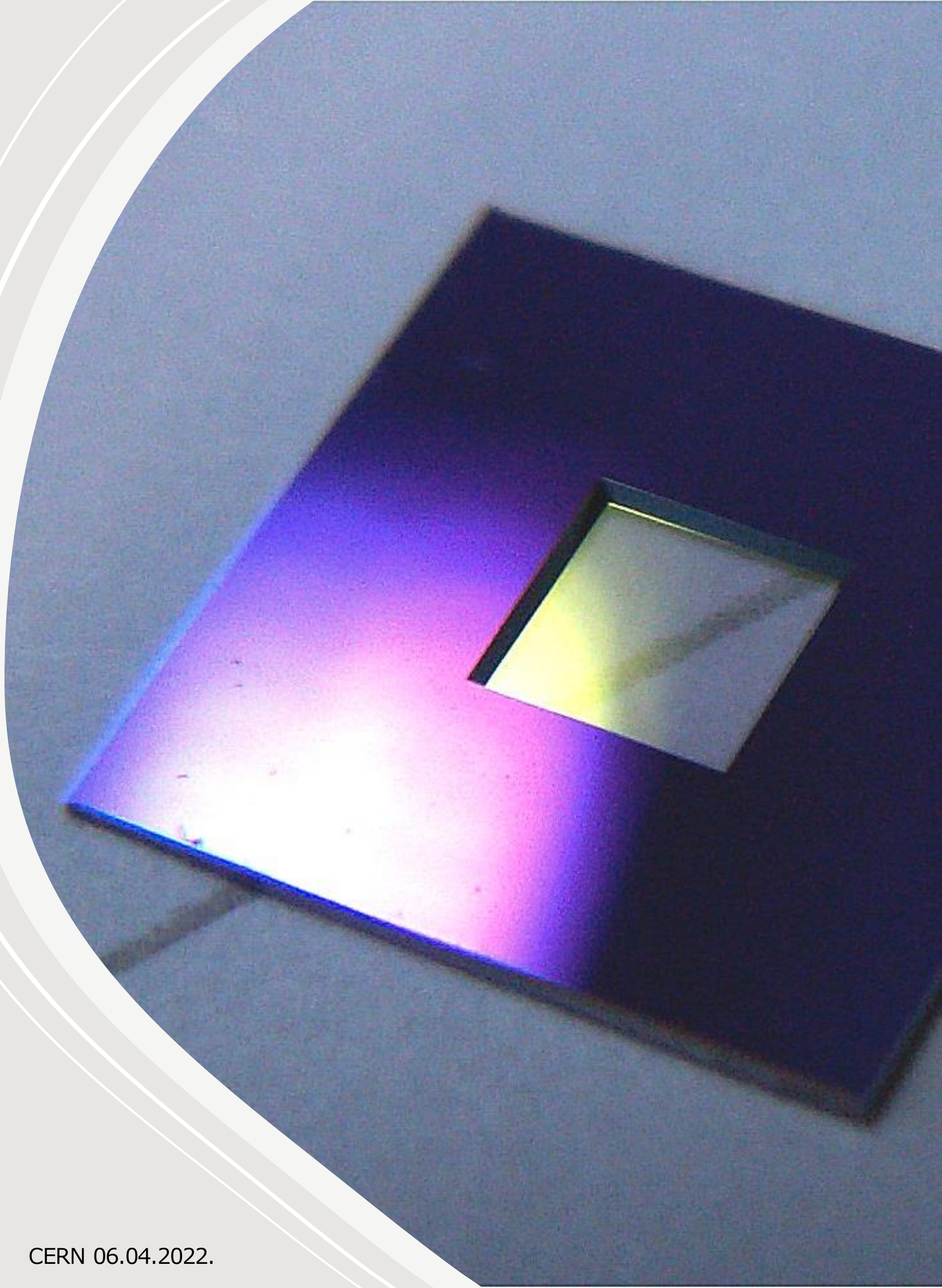
E. Serra, M. Bawaj, A. Borrielli, et al.



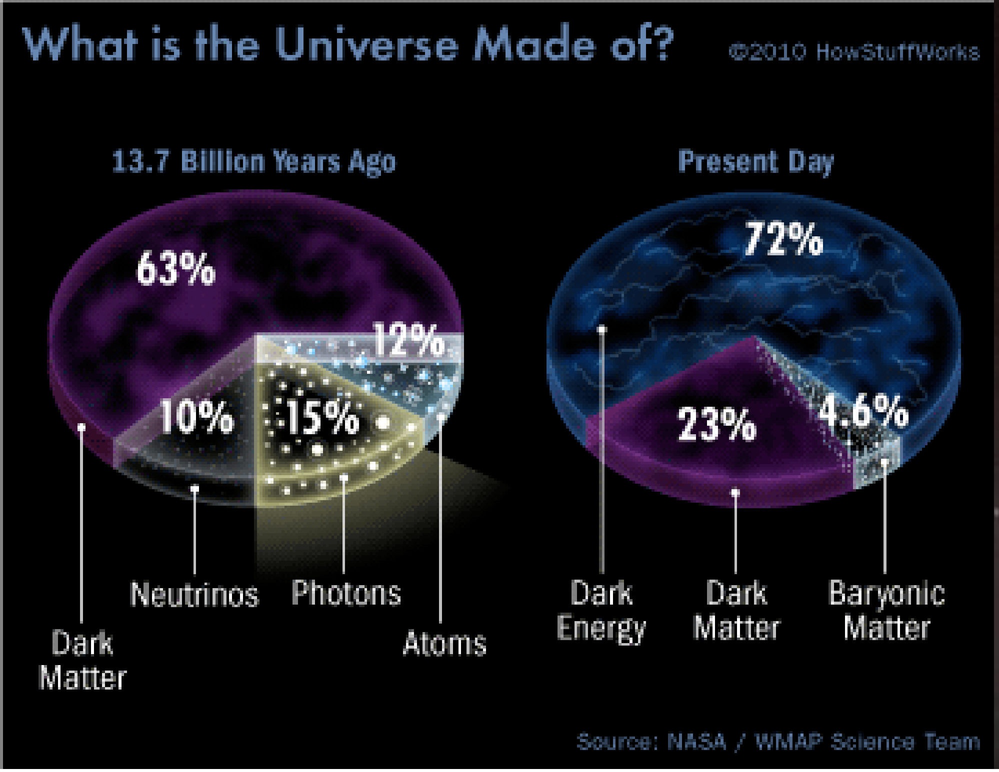
Start from one

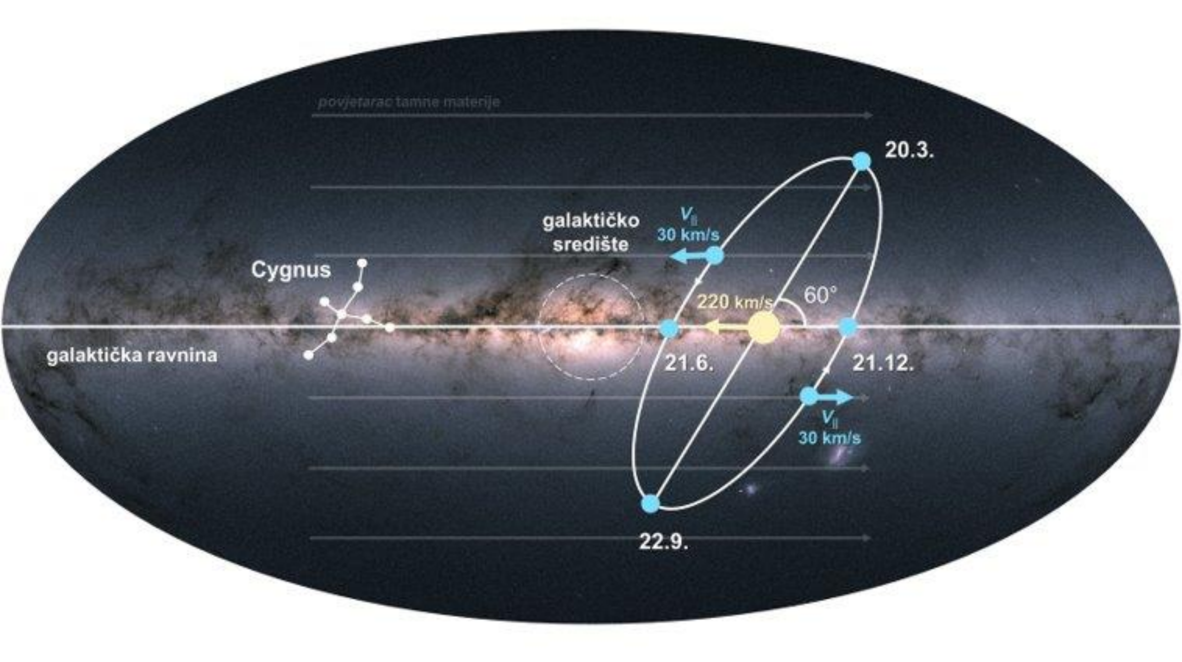
- high frequency and Q factor not the only requirement
- conductivity, density, mass …

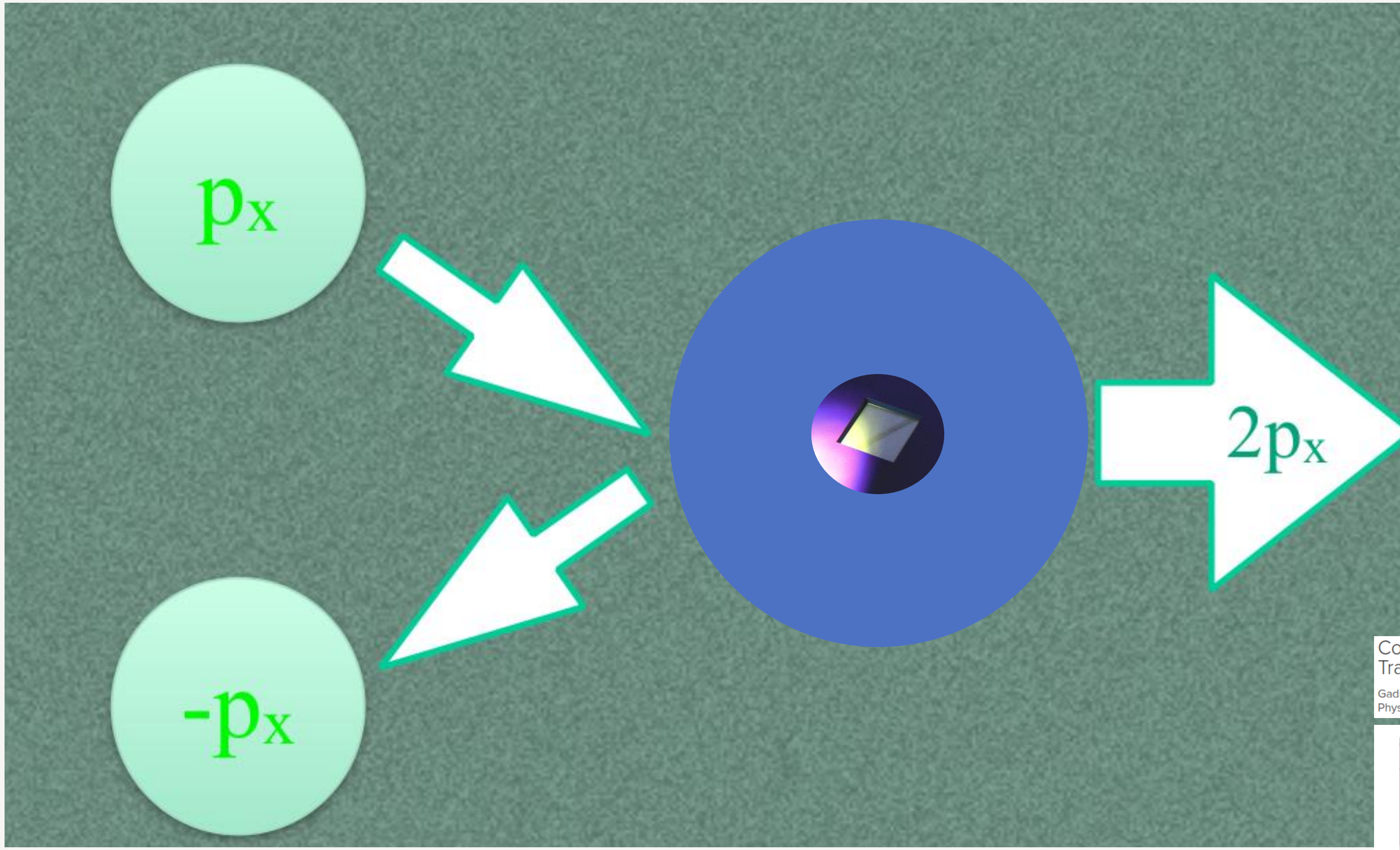
--> additional layers needed!



Motivation


What is the Universe Made of?
©2010 HowStuffWorks
13.7 Billion Years Ago
63%
12%
10%
15%
Dark Matter
Neutrinos
Photons
Atoms
Present Day
72%
23%
4.6%
Dark Energy
Dark Matter
Baryonic Matter
Source: NASA / WMAP Science Team


povjetarac tamne materije
20.3.
galaktičko središte
$V_{\parallel}$ 30 km/s
Cygnus
220 km/s
60°
galaktička ravnina
21.6.
21.12.
$V_{\parallel}$ 30 km/s
22.9.



Develop a radiation pressure detector!

-measure momentum transfer
- high sensitivty

Coherent Scattering of Low Mass Dark Matter from Optically Trapped Sensors

Gadi Afek, Daniel Carney, and David C. Moore
Phys. Rev. Lett. **128**, 101301 – Published 9 March 2022

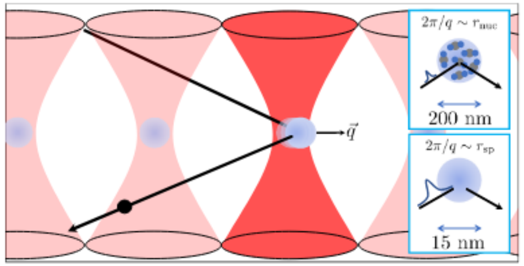


FIG. 1. As a dark matter particle scatters from a levitated optomechanical sensor (possibly part of a large array), it transfers to it momentum $\vec{q}$. For "large" sensors (upper inset) the interaction is coherent over a single nucleus. For "small" enough sensors, such that the inverse transferred momentum $2\pi/q$ of the dark matter particle is comparable to the size of the sensor, the interaction is coherent over the entire sensor, leading to a large increase in scattering cross-section.

Start from one

- PECS II System

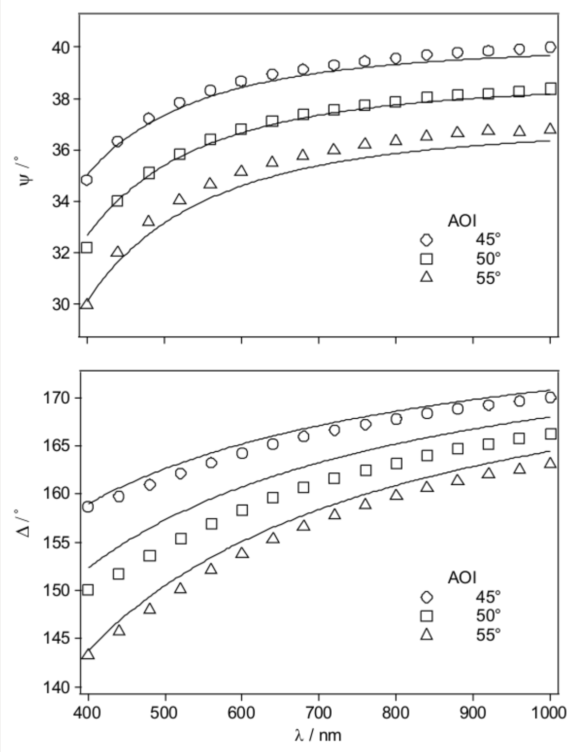
Broad argon ion beam system designed to polish and coat samples for SEM imaging and analytical techniques.

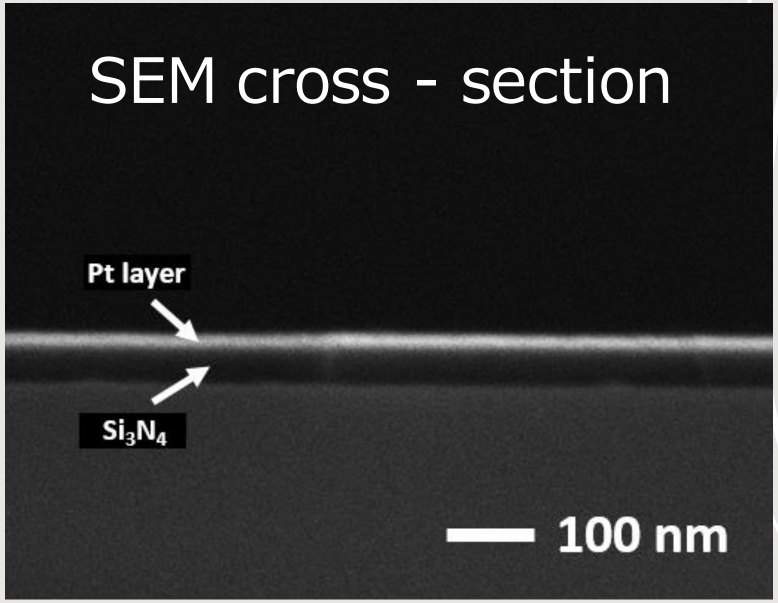
--> Pt layer

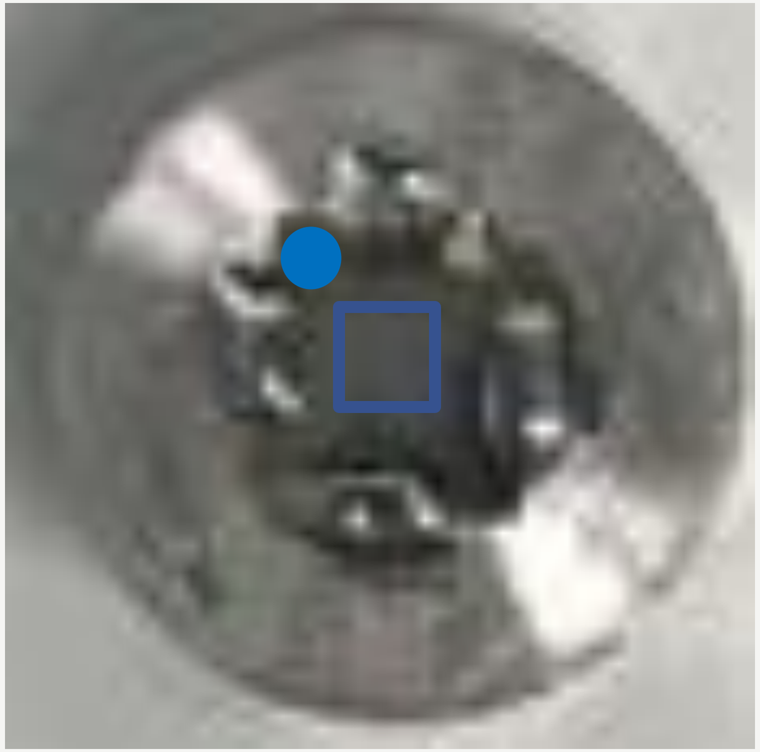
Not working for large area membranes

Start from one

Ellipsometry 45 nm + 13 Pt



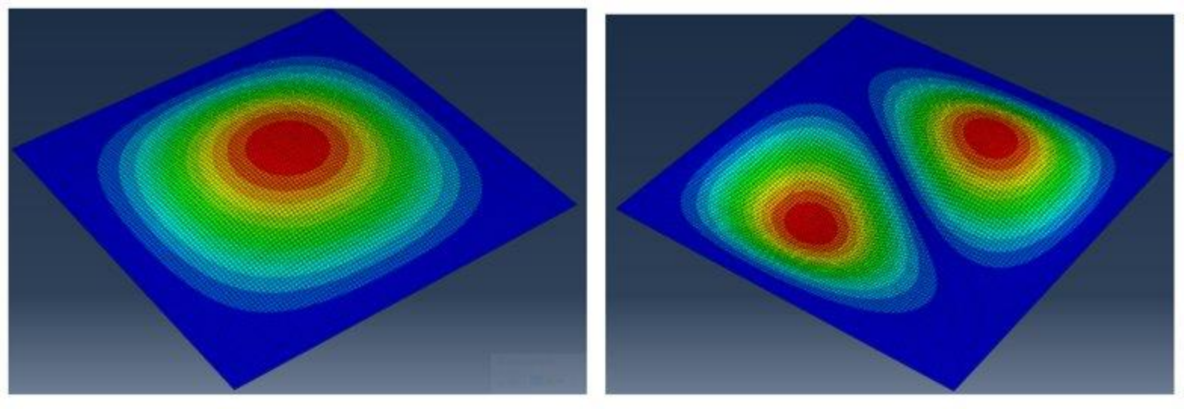




- different thickness from nominal

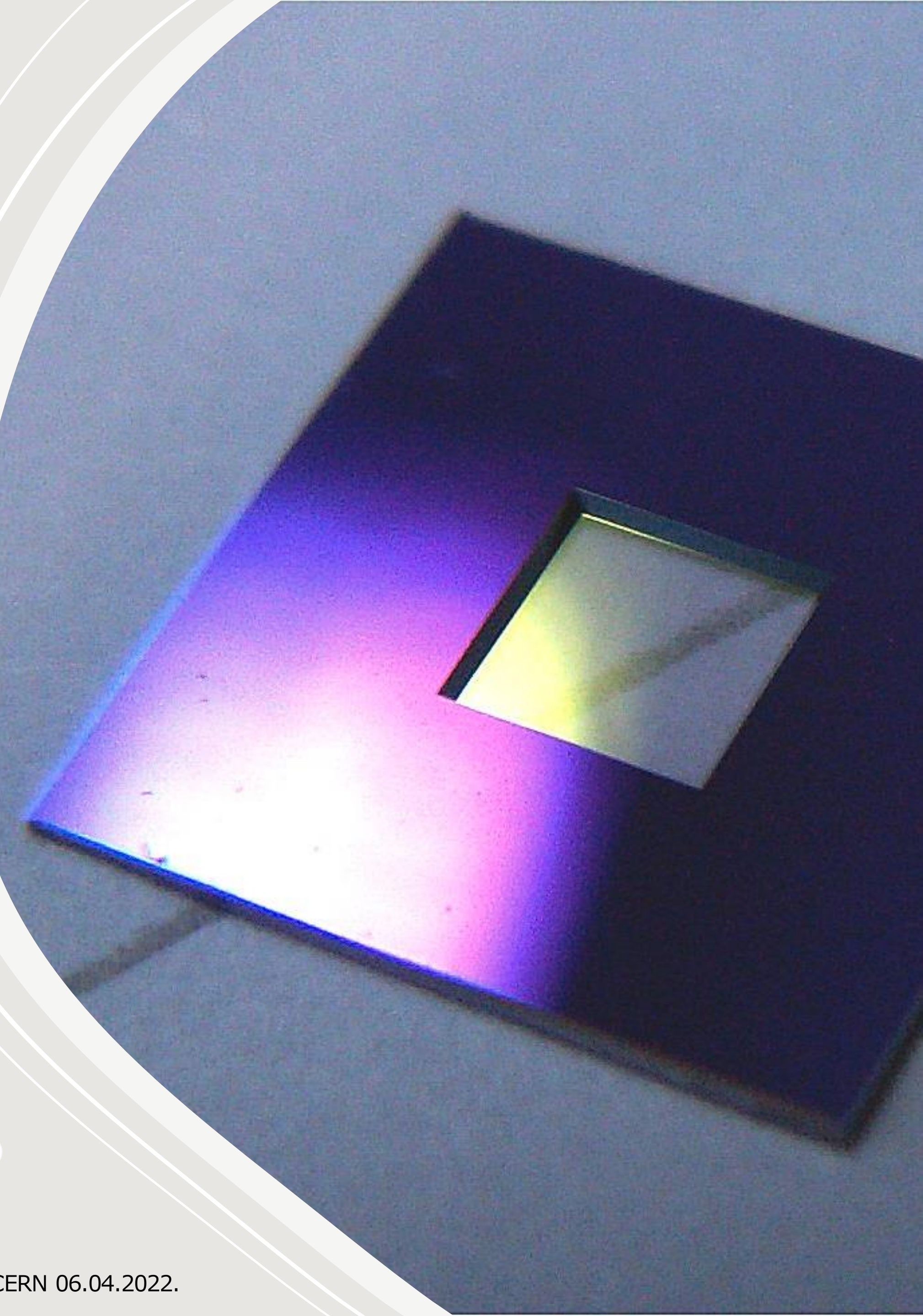
Start from one

FEM simulation 50 nm + 15 Pt



- discrepancy between simulation and experiment
- measured resonant frequency lower than simulation

- metallic layer introduces additional loss channel
- implantation of Pt atoms in Si_3N_4

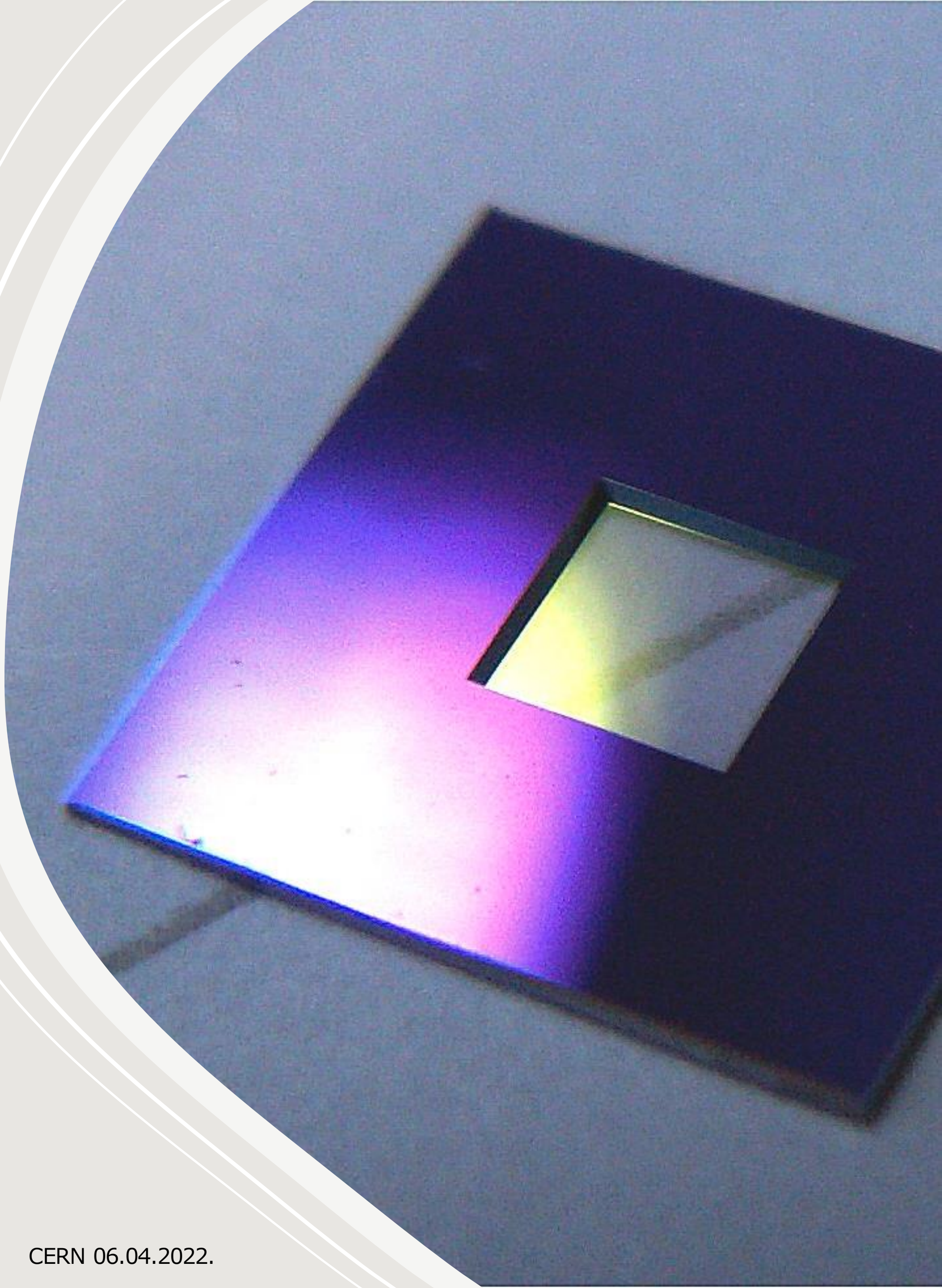


Conclusion and outlook

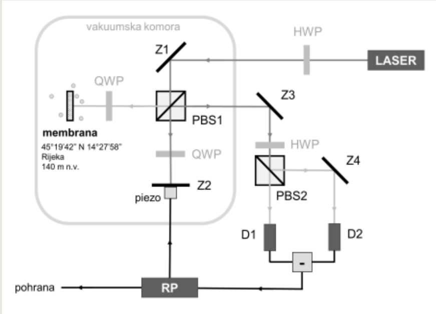
- test other coatings and techniques
- first tests with ALD

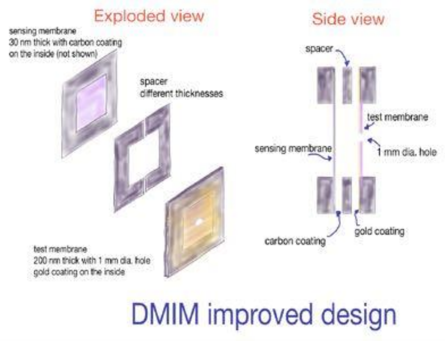
- optimized mechanical design

- promising sensors



Conclusion and outlook





DMIM improved design

DIRECTIONAL DARK MATTER

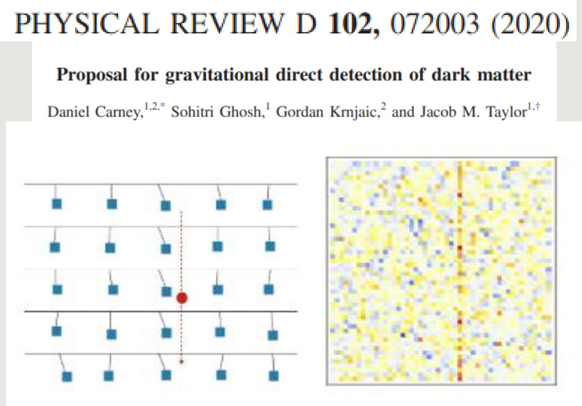
DETECTOR- GALACTIC HALO

Dark matter induced Brownian motion

Ting Cheng, Reinard Primulando & Martin Spinrath

The European Physical Journal C **80**, Article number: 519 (2020) | Cite this article

GRAVITATIONAL DETECTION



PHYSICAL REVIEW D **102**, 072003 (2020)

Proposal for gravitational direct detection of dark matter

Daniel Carney,[1,2,*] Sohitri Ghosh,[1] Gordan Krnjaic,[2] and Jacob M. Taylor[1,†]

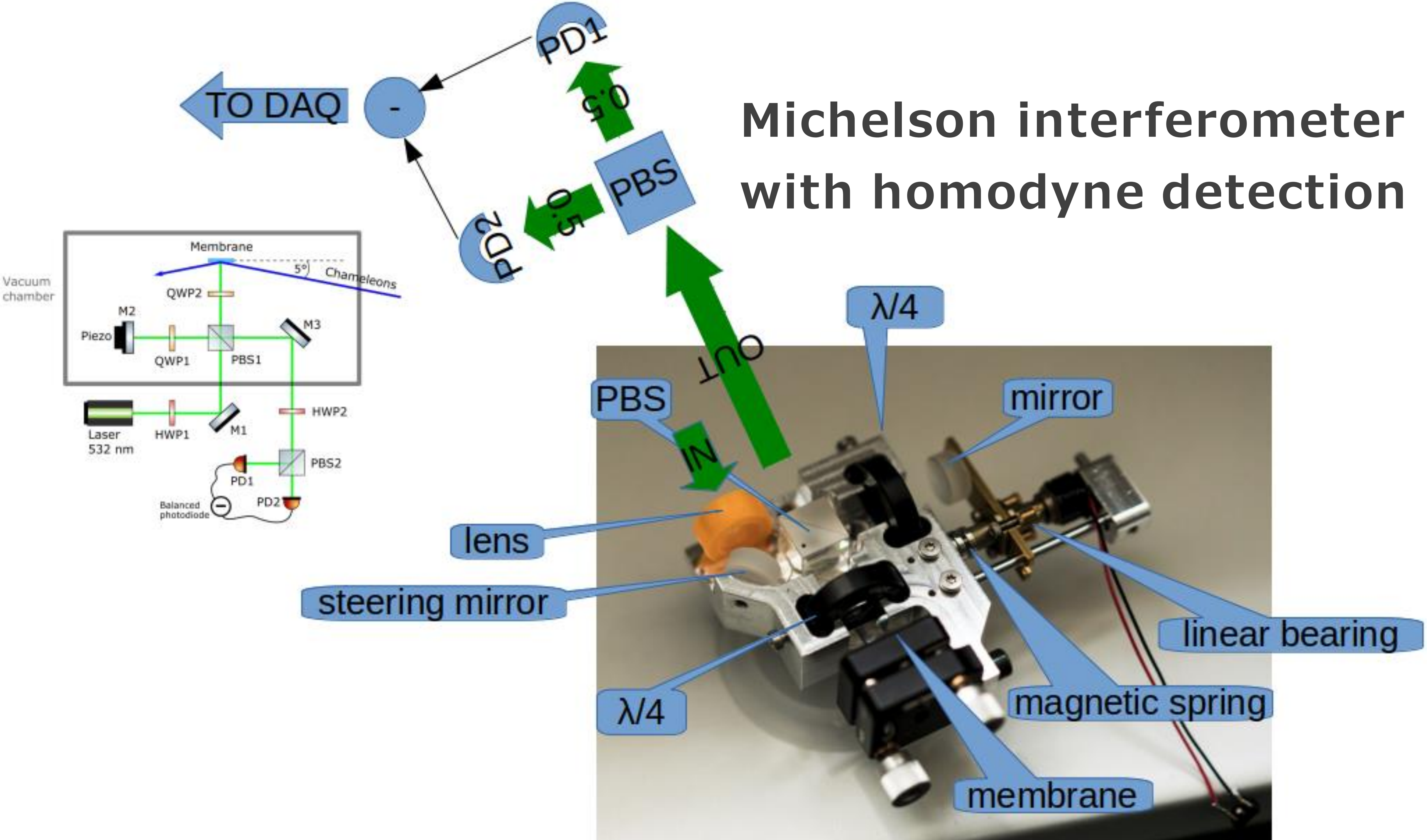
CASIMIR FORCE

MODIFICATION

Force sensor for chameleon and Casimir force experiments with parallel-plate configuration

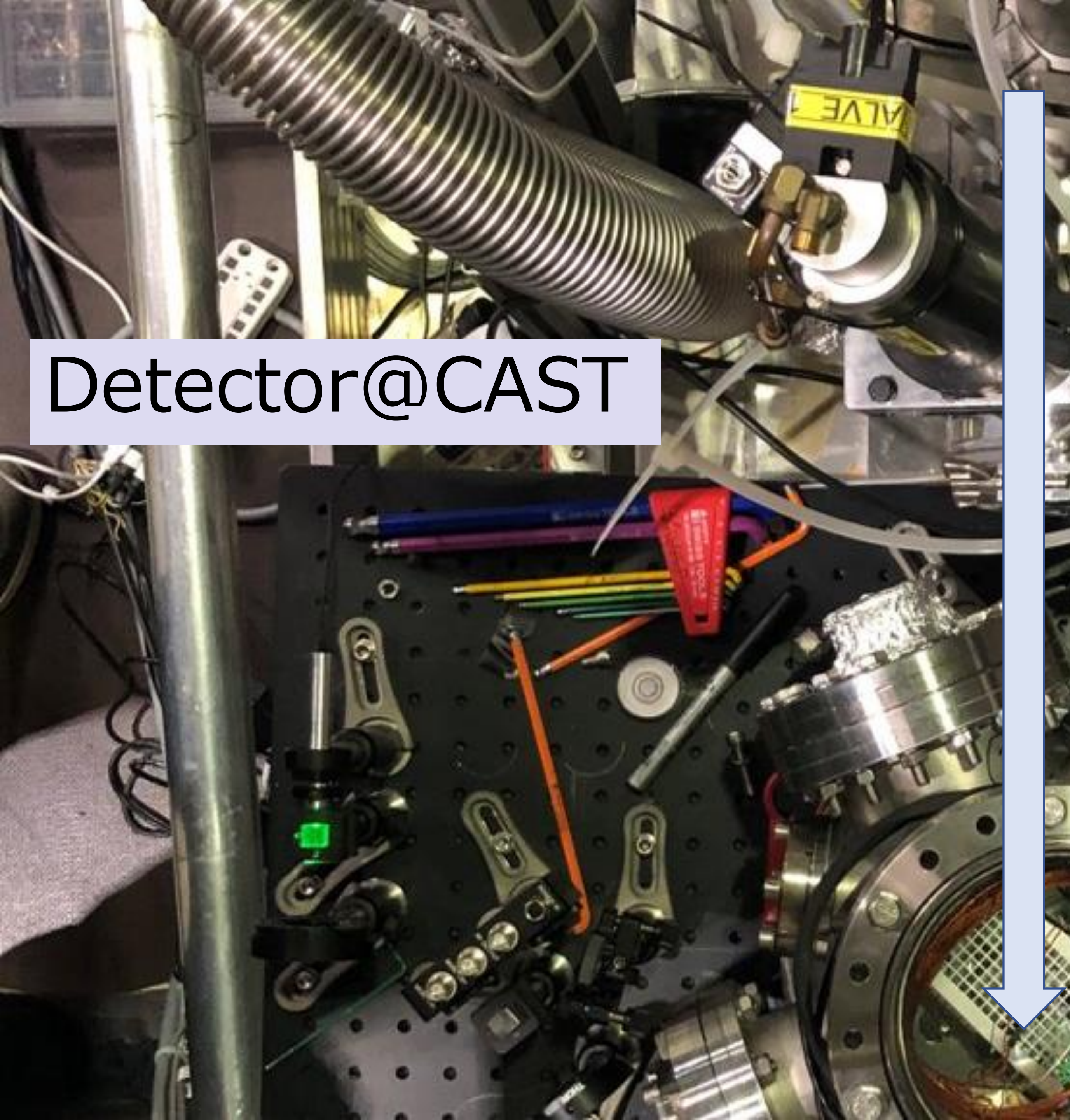
Attaallah Almasi, Philippe Brax, Davide Iannuzzi, and René I. P. Sedmik
Phys. Rev. D **91**, 102002 – Published 7 May 2015

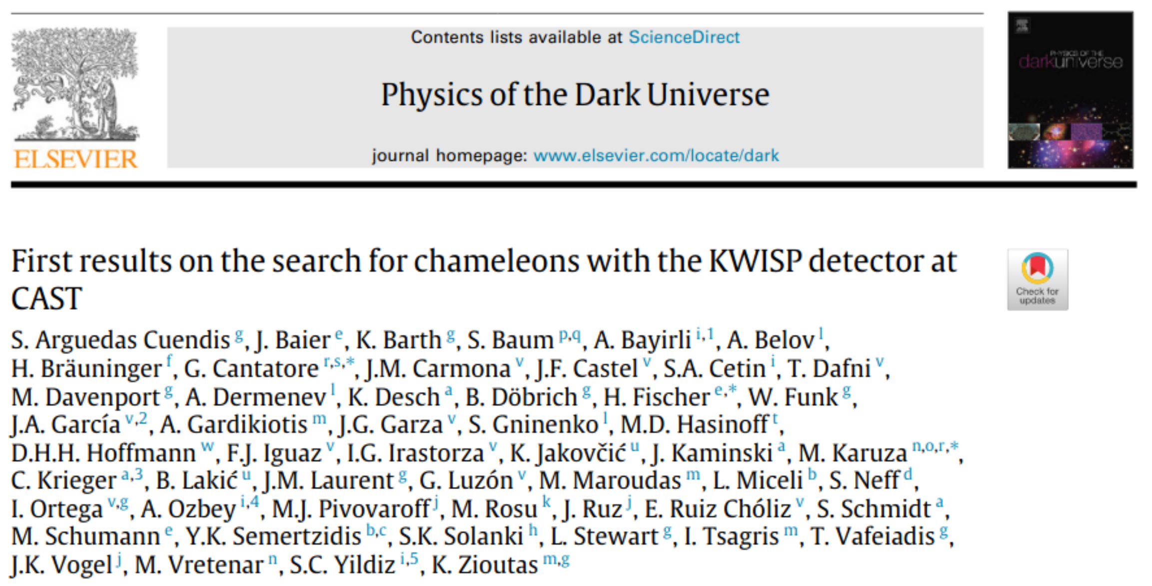
Michelson interferometer with homodyne detection



CAST – CERN Axion Solar Telescope

Detector@CAST




Contents lists available at ScienceDirect

Physics of the Dark Universe

journal homepage: www.elsevier.com/locate/dark

First results on the search for chameleons with the KWISP detector at CAST

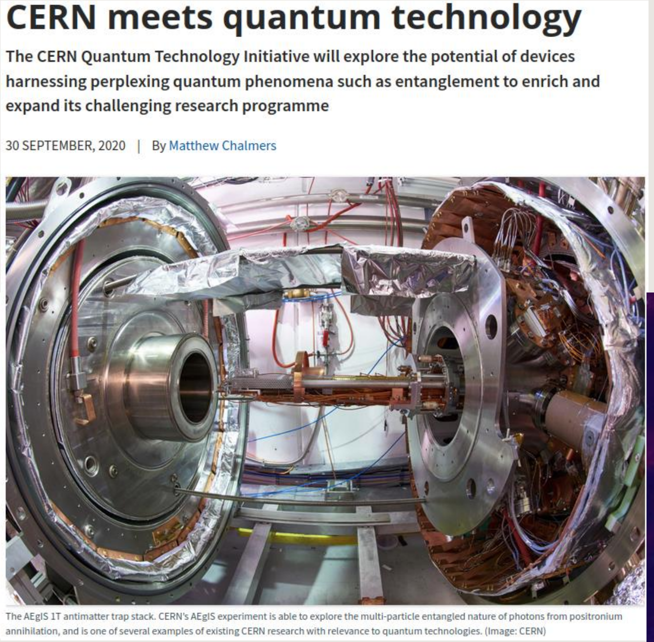
S. Arguedas Cuendis[g], J. Baier[e], K. Barth[g], S. Baum[p,q], A. Bayirli[i,1], A. Belov[l], H. Bräuninger[f], G. Cantatore[r,s,*], J.M. Carmona[v], J.F. Castel[v], S.A. Cetin[i], T. Dafni[v], M. Davenport[g], A. Dermenev[l], K. Desch[a], B. Döbrich[g], H. Fischer[e,*], W. Funk[g], J.A. García[v,2], A. Gardikiotis[m], J.G. Garza[v], S. Gninenko[l], M.D. Hasinoff[t], D.H.H. Hoffmann[w], F.J. Iguaz[v], I.G. Irastorza[v], K. Jakovčić[u], J. Kaminski[a], M. Karuza[n,o,r,*], C. Krieger[a,3], B. Lakić[u], J.M. Laurent[g], G. Luzón[v], M. Maroudas[m], L. Miceli[b], S. Neff[d], I. Ortega[v,g], A. Ozbey[i,4], M.J. Pivovaroff[j], M. Rosu[k], J. Ruz[j], E. Ruiz Chóliz[v], S. Schmidt[a], M. Schumann[e], Y.K. Semertzidis[b,c], S.K. Solanki[h], L. Stewart[g], I. Tsagris[m], T. Vafeiadis[g], J.K. Vogel[j], M. Vretenar[n], S.C. Yildiz[i,5], K. Zioutas[m,g]

Conclusion

CERN Quantum Technology Initiative unveils strategic roadmap shaping CERN's role in next quantum revolution

CERN QTI reaches its next milestone today, with the unveiling of a first roadmap defining its medium- and long-term quantum research programme

14 OCTOBER, 2021

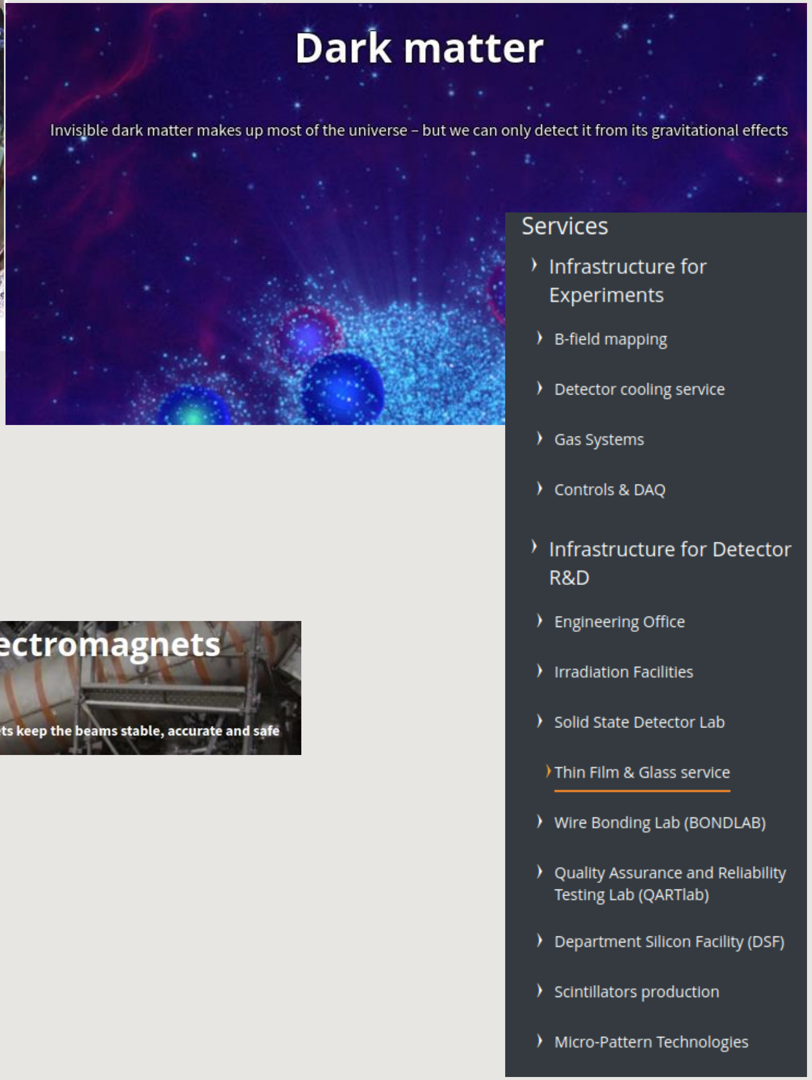


CERN meets quantum technology

The CERN Quantum Technology Initiative will explore the potential of devices harnessing perplexing quantum phenomena such as entanglement to enrich and expand its challenging research programme

30 SEPTEMBER, 2020 | By Matthew Chalmers

The AEgIS 1T antimatter trap stack. CERN's AEgIS experiment is able to explore the multi-particle entangled nature of photons from positronium annihilation, and is one of several examples of existing CERN research with relevance to quantum technologies. (Image: CERN)



Dark matter

Invisible dark matter makes up most of the universe – but we can only detect it from its gravitational effects

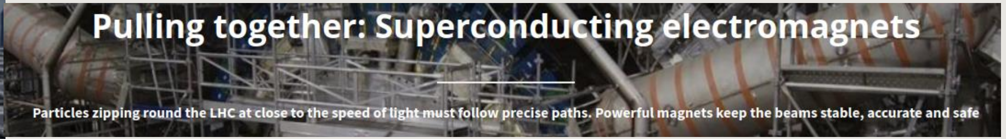
Services

- Infrastructure for Experiments
  - B-field mapping
  - Detector cooling service
  - Gas Systems
  - Controls & DAQ
- Infrastructure for Detector R&D
  - Engineering Office
  - Irradiation Facilities
  - Solid State Detector Lab
  - Thin Film & Glass service
  - Wire Bonding Lab (BONDLAB)
  - Quality Assurance and Reliability Testing Lab (QARTlab)
  - Department Silicon Facility (DSF)
  - Scintillators production
  - Micro-Pattern Technologies

Science › Computing › Data centre

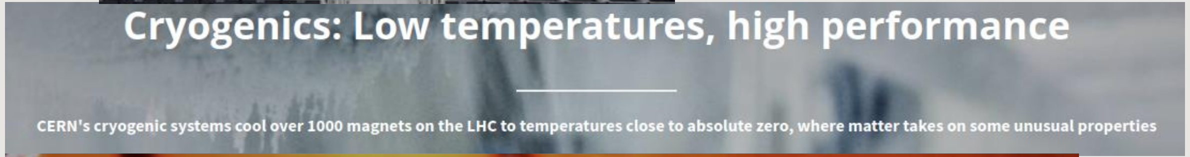
CERN Data Centre

At the heart of CERN's infrastructure



Pulling together: Superconducting electromagnets

Particles zipping round the LHC at close to the speed of light must follow precise paths. Powerful magnets keep the beams stable, accurate and safe



Cryogenics: Low temperatures, high performance

CERN's cryogenic systems cool over 1000 magnets on the LHC to temperatures close to absolute zero, where matter takes on some unusual properties

A vacuum as empty as interstellar space

With the first start-up of beams in 2008, the Large Hadron Collider (LHC) became the biggest operational vacuum system in the world

CENTAR ZA MIKRO- I NANOZNANOSTI I TEHNOLOGIJE

ODJEL ZA FIZIKU
DEPARTMENT OF PHYSICS
Sveučilište u Rijeci
University of Rijeka

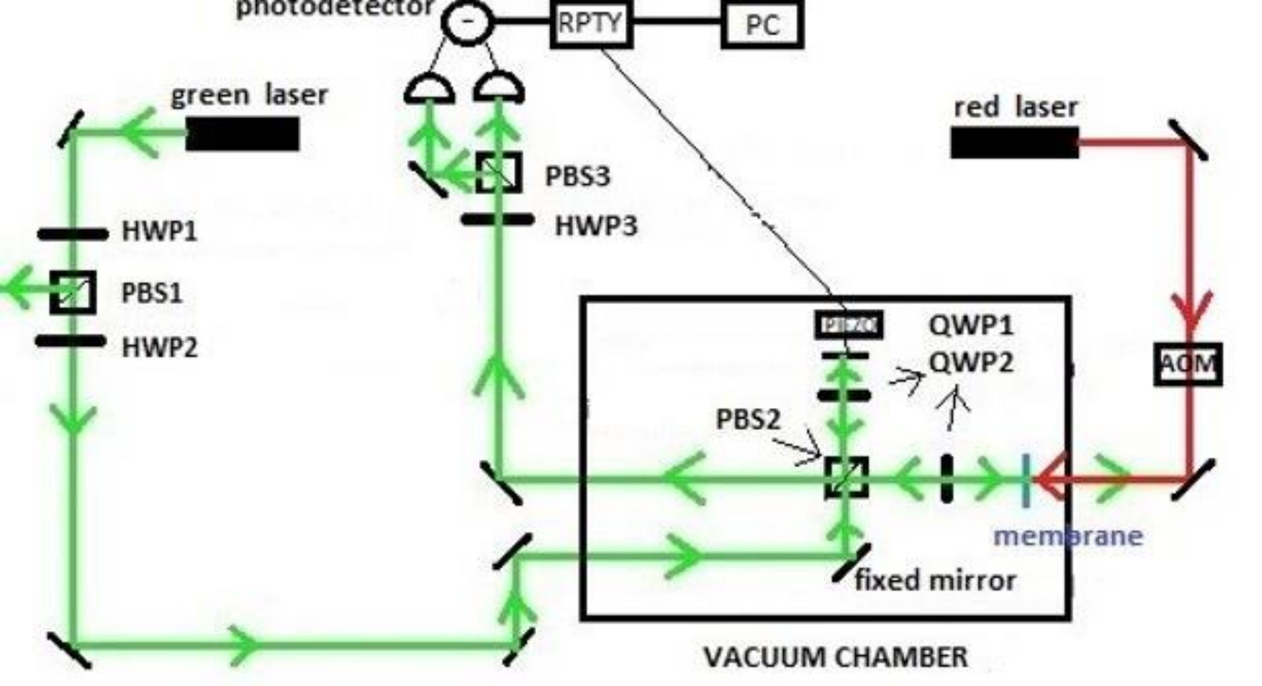
CEMS
Center of Excellence for Advanced Materials and Sensing Devices

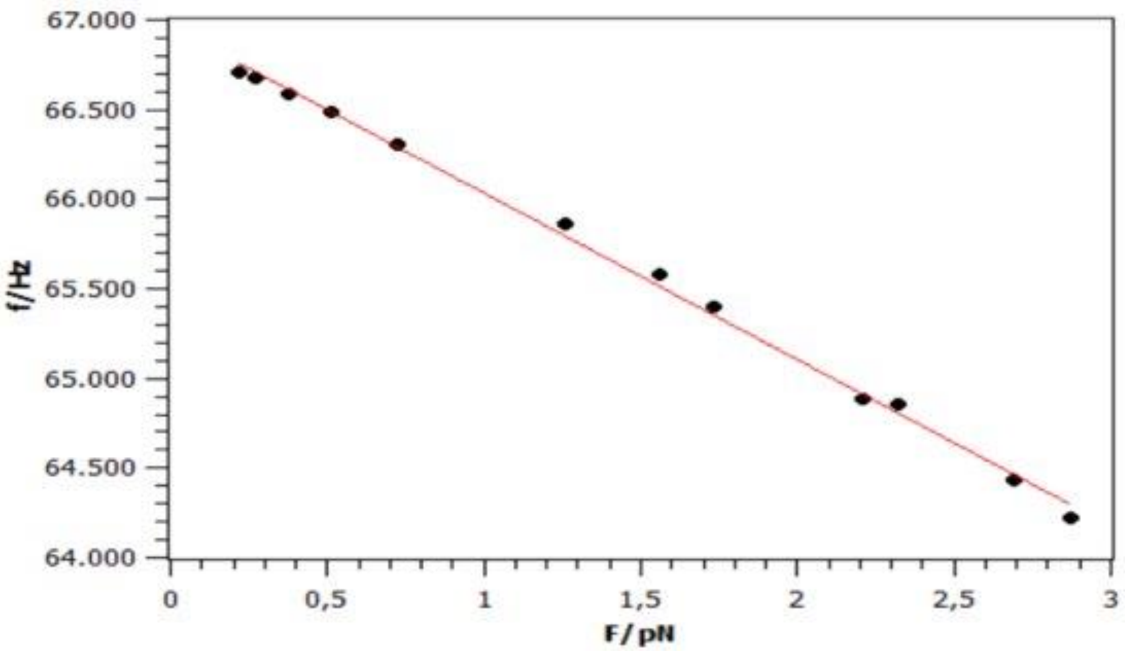
We acknowledge support from University of Rijeka with grant no 13.12.2.2.09, 18-126, EU fund projects KK.01.1.1.01.0001 and RC.2.2.06.-0001. The authors express their gratitude to the colleagues of the INFN Sezione di Trieste mechanical workshop where parts of the detector were built.

STRUKTURNI I INVESTICIJSKI FONDOVI

Ministarstvo znanosti i obrazovanja

KONKURENTNA HRVATSKA





Force calibration

- radiation pressure from 2 mW HeNe red laser
- 3 pN force / resolution ~fN

Dark Energy

- accelerated expansion of the Universe

$$V_{\text{eff}}(\phi) = \Lambda^4\left(1 + \frac{\Lambda^n}{\phi^n}\right) + \rho_m e^{\frac{\beta_m \phi}{M_{\text{Pl}}}} + \frac{1}{4}F_{\mu\nu}F^{\mu\nu}e^{\frac{\beta_\gamma \phi}{M_{\text{Pl}}}}$$

$$m_{\text{eff}}^2 = (n+1)\,\frac{\beta_m \rho_m}{M_{\text{Pl}}}\,\frac{1}{\phi_{\text{min}}}$$