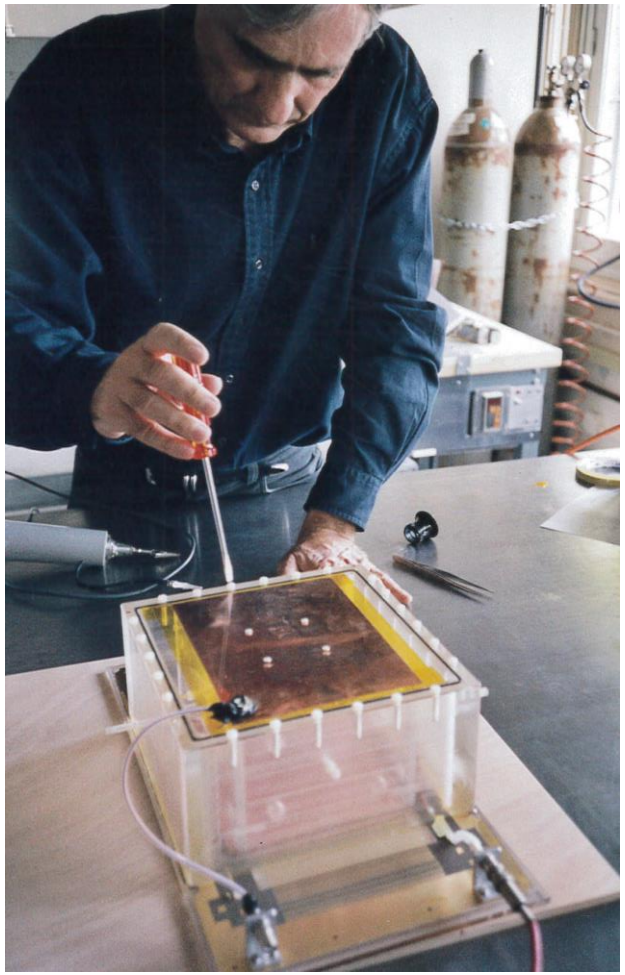
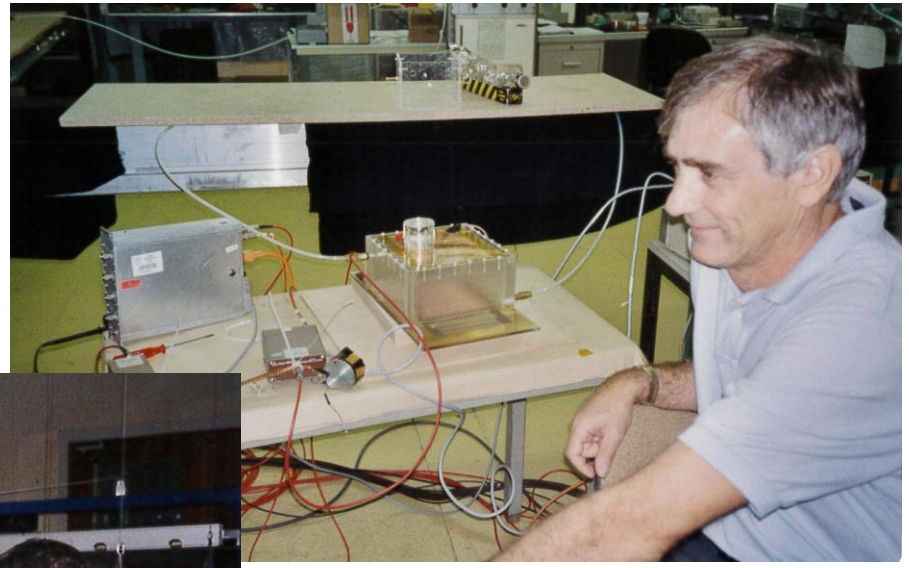
Ioannis and Micromegas for rare event detection

Theopisti Dafni and Igor G. Irastorza (CAPA – U. of Zaragoza)

Celebrating Ioannis, 5th October 2023, CEA/Saclay

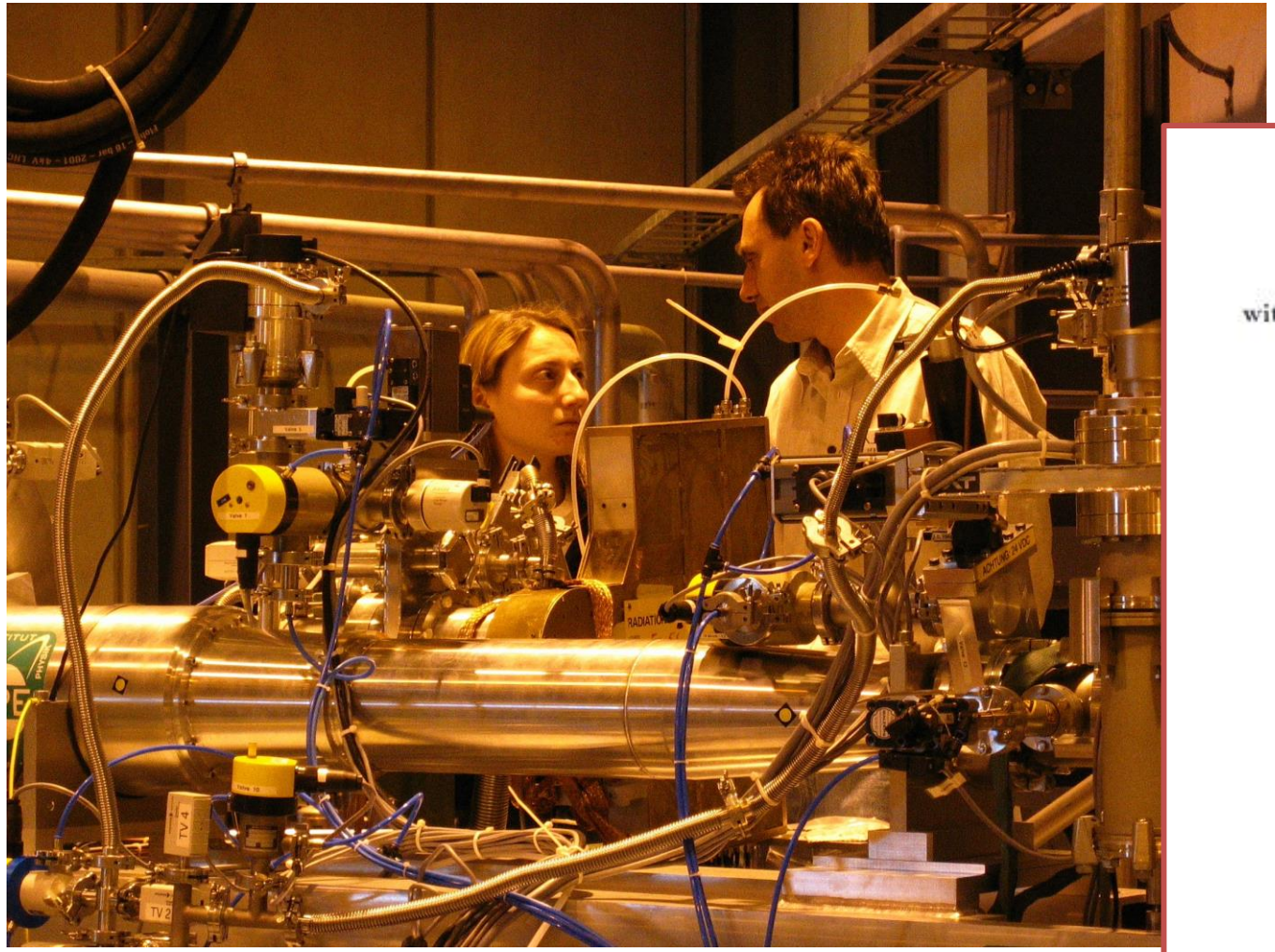
It all started here…



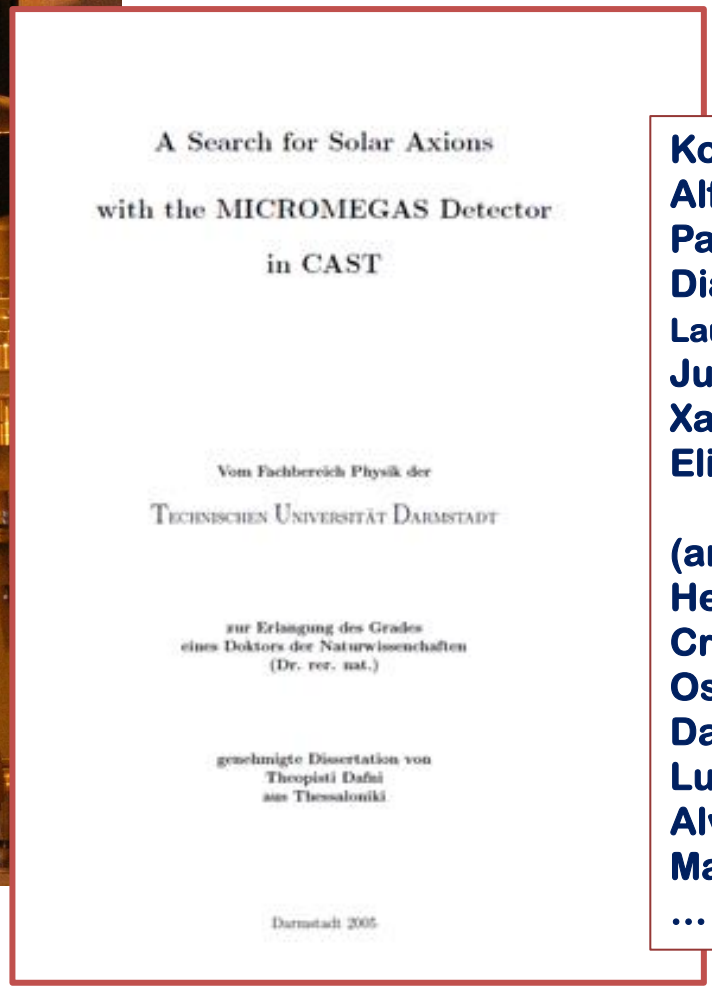


Sept-2000

First MMs in CAST @ CERN



First "Micromegas for RE" PhD thesis
It was followed by many more…



A Search for Solar Axions

with the MICROMEGAS Detector

in CAST

Vom Fachbereich Physik der

Technischen Universität Darmstadt

zur Erlangung des Grades
eines Doktors der Naturwissenschaften
(Dr. rer. nat.)

genehmigte Dissertation von
Theopisti Dafni
aus Thessaloniki

Darmstadt 2005

Kostas Koussuris
Alfredo Tomas,
Paco Iguaz,
Diana Herrera,
Laura Seguí,
Juanan García,
Xavi Gracia,
Elisa Ruiz-Chóliz,

(and in progress…)
Hector Mirallas,
Cristina Margalejo,
Oscar Pérez,
David Díez,
Luis Obis,
Alvaro Ezquerro,
María Jiménez
…

First MMs in CAST @ CERN

From most-cited paper…

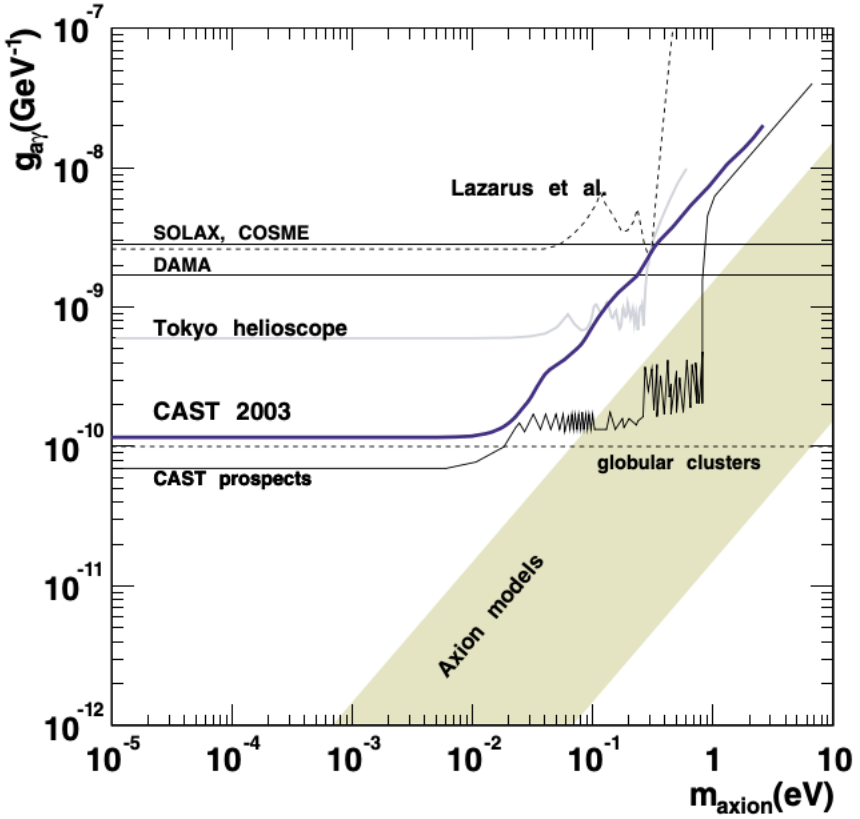
- **First CAST physics result 2005: most cited axion experimental paper until 2018**

PRL **94,** 121301 (2005) PHYSICAL REVIEW LETTERS week ending 1 APRIL 2005

First Results from the CERN Axion Solar Telescope

K. Zioutas,[8] S. Andriamonje,[2] V. Arsov,[13,4] S. Aune,[2] D. Autiero,[1,*] F. T. Avignone,[3] K. Barth,[1] A. Belov,[11] B. Beltrán,[6] H. Bräuninger,[5] J. M. Carmona,[6] S. Cebrián,[6] E. Chesi,[1] J. I. Collar,[7] R. Creswick,[3] T. Dafni,[4] M. Davenport,[1] L. Di Lella,[1,†] C. Eleftheriadis,[8] J. Englhauser,[5] G. Fanourakis,[9] H. Farach,[3] E. Ferrer,[2] H. Fischer,[10] J. Franz,[10] P. Friedrich,[5] T. Geralis,[9] I. Giomataris,[2] S. Gninenko,[11] N. Goloubev,[11] M. D. Hasinoff,[12] F. H. Heinsius,[10] D. H. H. Hoffmann,[4] I. G. Irastorza,[2] J. Jacoby,[13] D. Kang,[10] K. Königsmann,[10] R. Kotthaus,[14] M. Krčmar,[15] K. Kousouris,[9] M. Kuster,[5] B. Lakić,[15] C. Lasseur,[1] A. Liolios,[8] A. Ljubičić,[15] G. Lutz,[14] G. Luzón,[6] D. W. Miller,[7] A. Morales,[6,‡] J. Morales,[6] M. Mutterer,[4] A. Nikolaidis,[8] A. Ortiz,[6] T. Papaevangelou,[1] A. Placci,[1] G. Raffelt,[14] J. Ruz,[6] H. Riege,[4] M. L. Sarsa,[6] I. Savvidis,[8] W. Serber,[14] P. Serpico,[14] Y. Semertzidis,[4,§] L. Stewart,[1] J. D. Vieira,[7] J. Villar,[6] L. Walckiers,[1] and K. Zachariadou[9]

(CAST Collaboration)



…to most cited paper.

- **Last CAST (solar axion) paper in Nature physics 2017: currently most cited axion experimental paper**

ARTICLES
PUBLISHED ONLINE: 1 MAY 2017 | DOI: 10.1038/NPHYS4109
nature physics
OPEN

New CAST limit on the axion–photon interaction

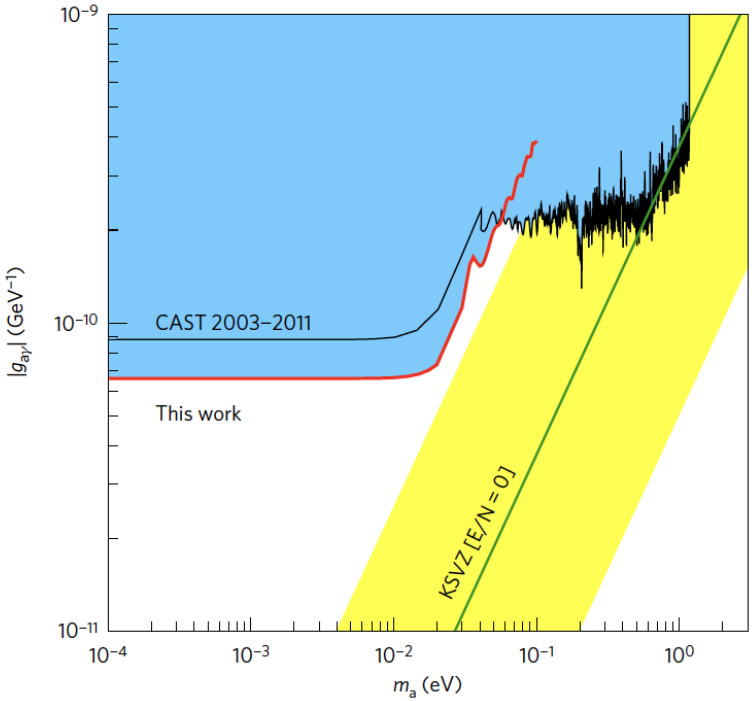
CAST Collaboration†

Hypothetical low-mass particles, such as axions, provide a compelling explanation for the dark matter in the universe. Such particles are expected to emerge abundantly from the hot interior of stars. To test this prediction, the CERN Axion Solar Telescope (CAST) uses a 9 T refurbished Large Hadron Collider test magnet directed towards the Sun. In the strong magnetic field, solar axions can be converted to X-ray photons which can be recorded by X-ray detectors. In the 2013–2015 run, thanks to low-background detectors and a new X-ray telescope, the signal-to-noise ratio was increased by about a factor of three. Here, we report the best limit on the axion–photon coupling strength (0.66 × 10^{-10} GeV^{-1} at 95% confidence level) set by CAST, which now reaches similar levels to the most restrictive astrophysical bounds.

Advancing the low-energy frontier is a key endeavour in the worldwide quest for particle physics beyond the standard model and in the effort to identify dark matter[1,2]. Nearly massless pseudoscalar bosons, often generically called axions, are particularly promising because they appear in many extensions of the standard model. They can be dark matter in the form of classical field oscillations that were excited in the early universe

previous CAST results. The low-mass part $m_a \lesssim 0.02$ eV corresponds to the first phase 2003–2004 using evacuated magnet bores[11,12]. The $a \to \gamma$ conversion probability in a homogeneous B field over a distance L is

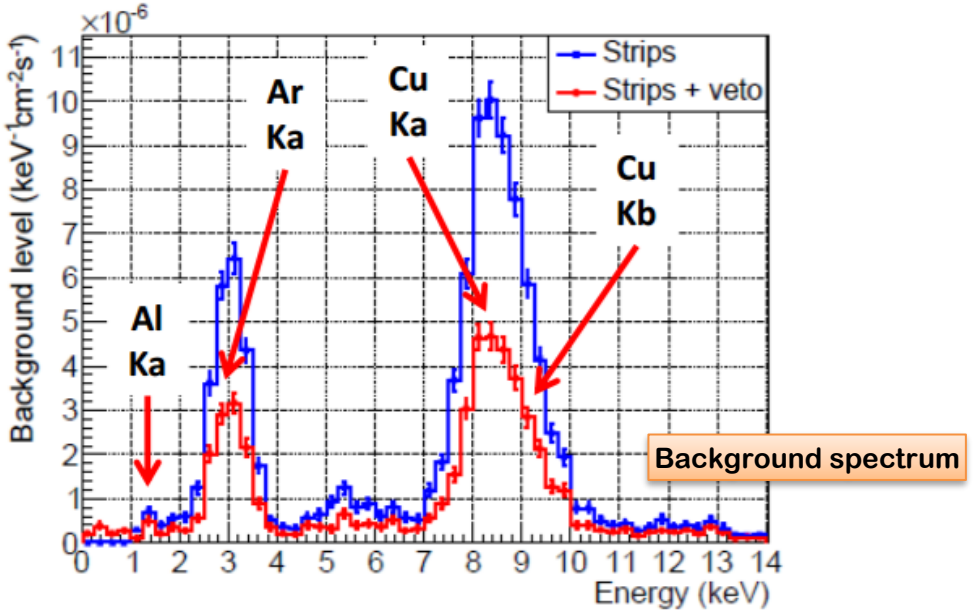
$$P_{a\to\gamma} = \left(g_{a\gamma} B \frac{\sin(qL/2)}{} \right)^2 \qquad (1)$$



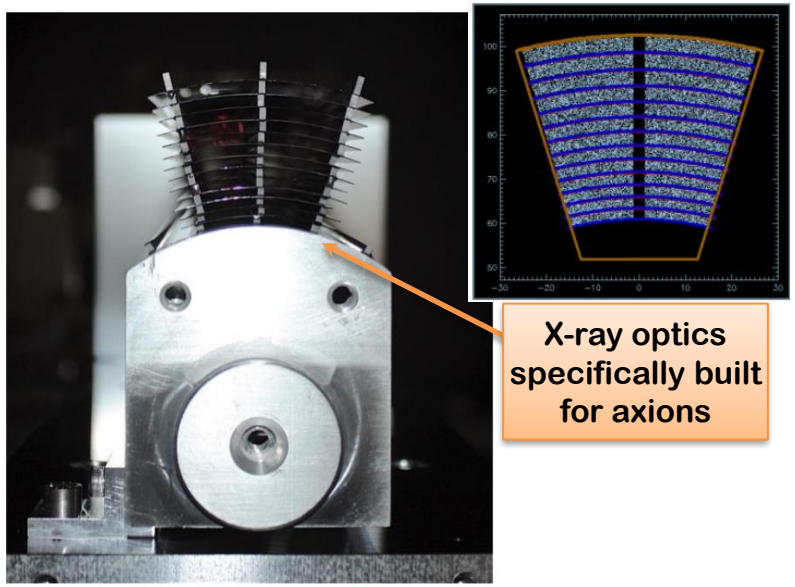
IAXO pathfinder at CAST

Test MM detector + slumped-glass x-ray optics together

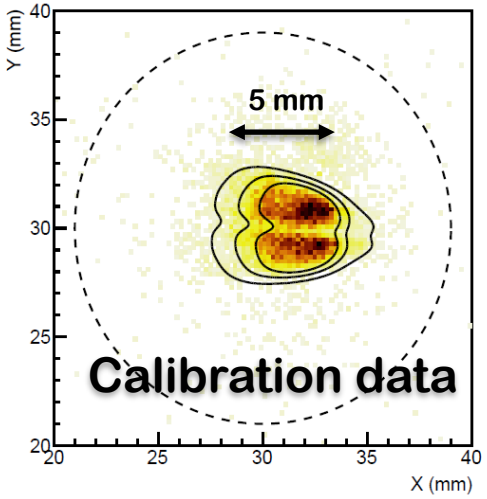
Detector: JCAP12 (2015)
Physics: Nature Phys. 13 (2017) 584-590

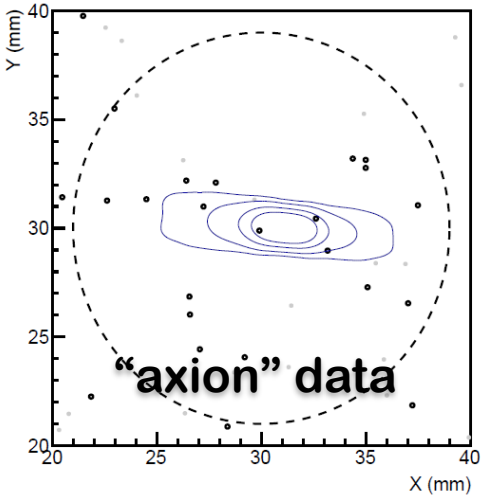


Background spectrum

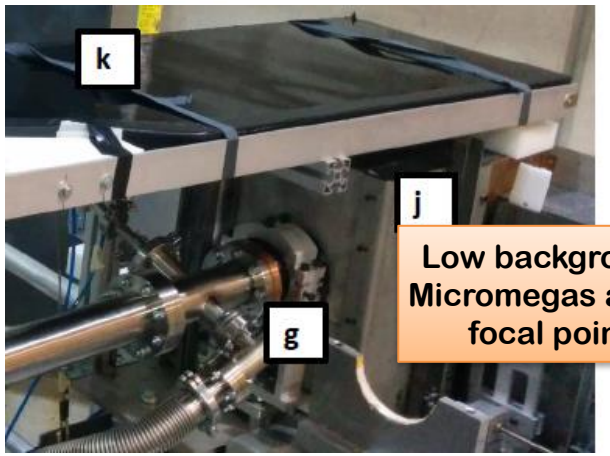


X-ray optics specifically built for axions





- Best SNR of any previous detector
- 290 tracking hour acquired (6.5 months operation)
- 3 counts observed in RoI (1 expected)



Low background Micromegas at the focal point

Going underground…

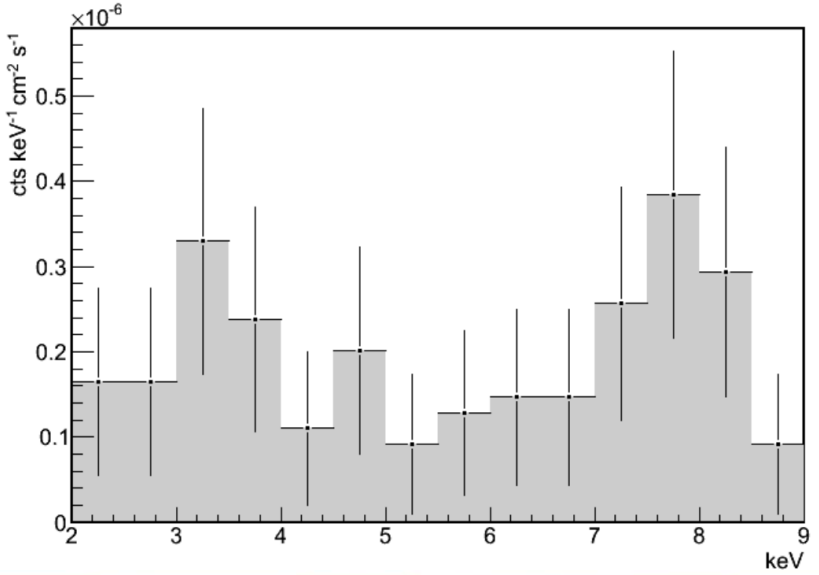
- **First tests of MM underground**

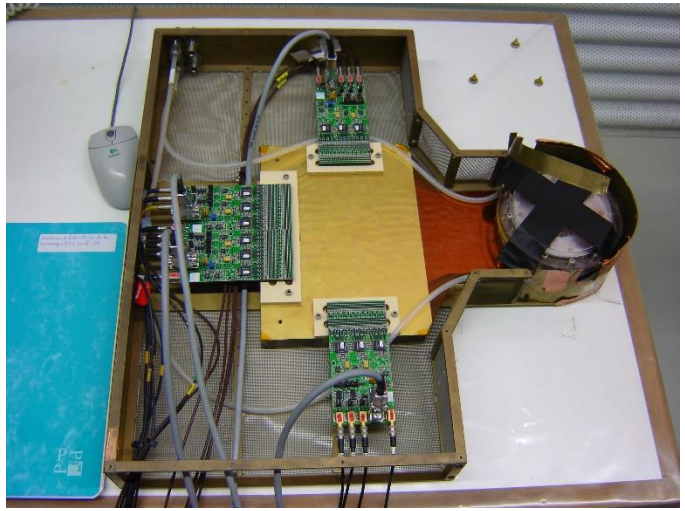
  (Modane 2002/3)

Going underground…

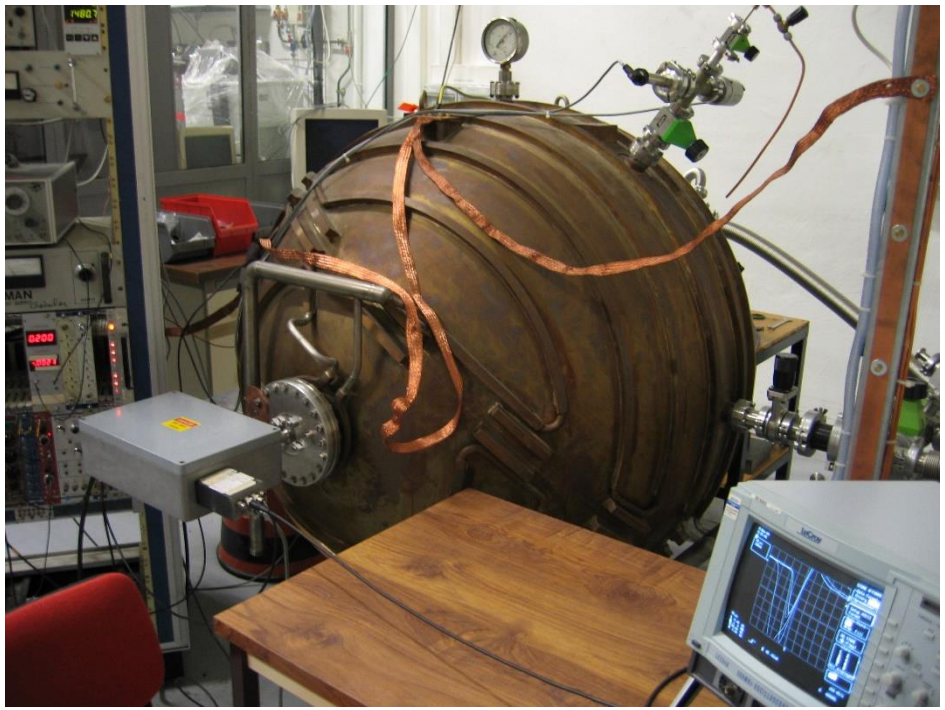
- **First CAST detector installed underground (Canfranc 2007)**

  (A. Tomás PhD thesis)





Beyond axions…



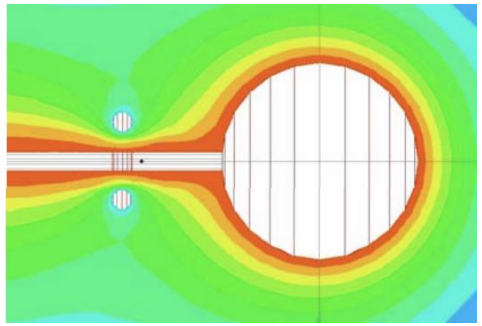
JINST
PUBLISHED BY INSTITUTE OF PHYSICS PUBLISHING AND SISSA
RECEIVED: *August 26, 2008*
ACCEPTED: *September 19, 2008*
PUBLISHED: *September 30, 2008*

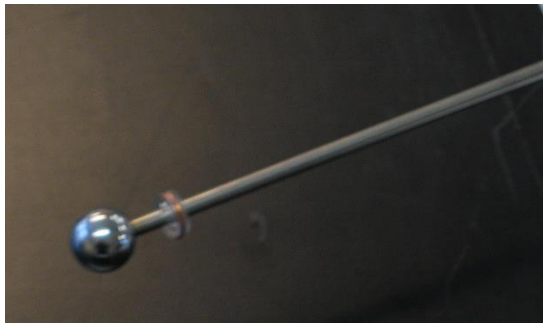
A novel large-volume spherical detector with proportional amplification read-out

I. Giomataris,[a*] I. Irastorza,[b] I. Savvidis,[c] S. Andriamonje,[a] S. Aune,[a] M. Chapellier,[a] Ph. Charvin,[a] P. Colas,[a] J. Derre,[a] E. Ferrer,[a] M. Gros,[a] X.F. Navick,[a] P. Salin[d] and J.D. Vergados[e]

[a] *IRFU, Centre d'études de Saclay, 91191 Gif sur Yvette CEDEX, France*
[b] *University of Saragoza, Spain*
[c] *Aristotle University of Thessaloniki, Greece*
[d] *APC, Université Paris 7 Denis Diderot, Paris, France*
[e] *University of Ioannina, Greece*
E-mail: ioanis.giomataris@cern.ch

2008 JIN

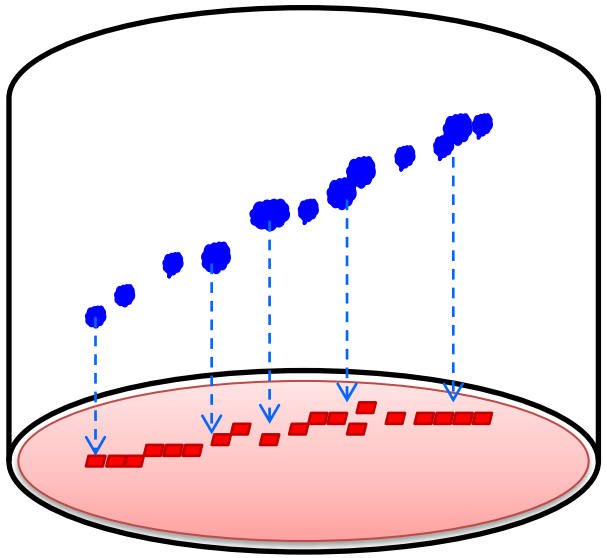




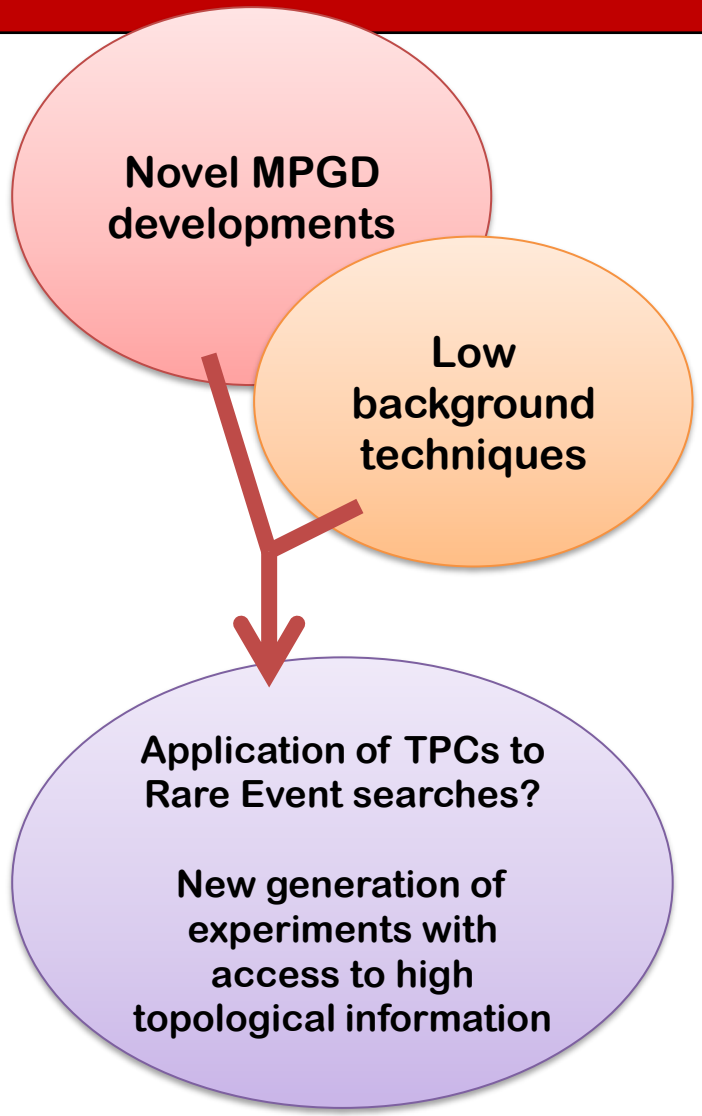
- **More on the spherical detector by Kostas**

… and T-REX

European Research Council
StG-2009: T-REX



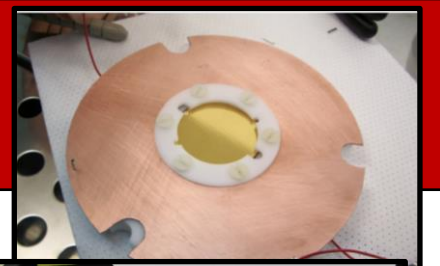
- Gas TPCs offer high potential for rare event through signal topology.
  - But, complex detector to reach high masses
- Novel readout techniques based on MPGD
- T-REX to merge MPGDs (=Micromegas) + low background expertise.
- Focus on exploratory R&D and small scale prototyping

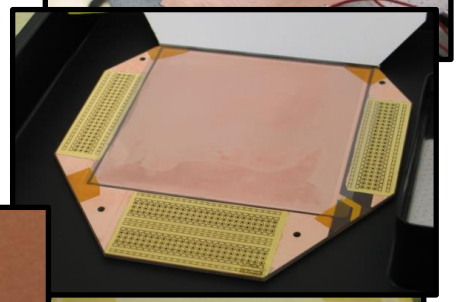


TREX outcome

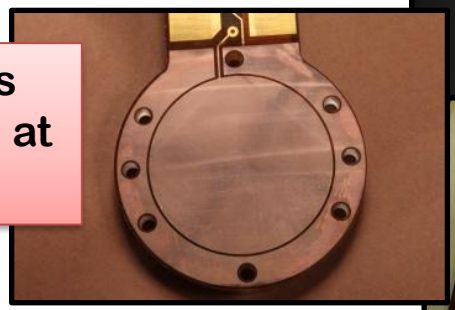
- **Generic R&D results:**
  - Radiopurity
  - Scalability
  - Topological information
  - Stability & energy resolution
  - Technical improvements & robustness
  - Software tools: REST-for-physics
- **Application in experiments:**
  - Axions: CAST & IAXO
  - $\beta\beta0\nu$: PandaX-III
  - WIMPs: TREX-DM (*)

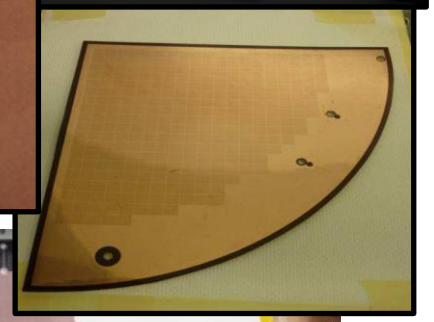
Summary of TREX results:
JCAP 1601 (2016) 01, 034
JCAP 1601 (2016) 01, 033

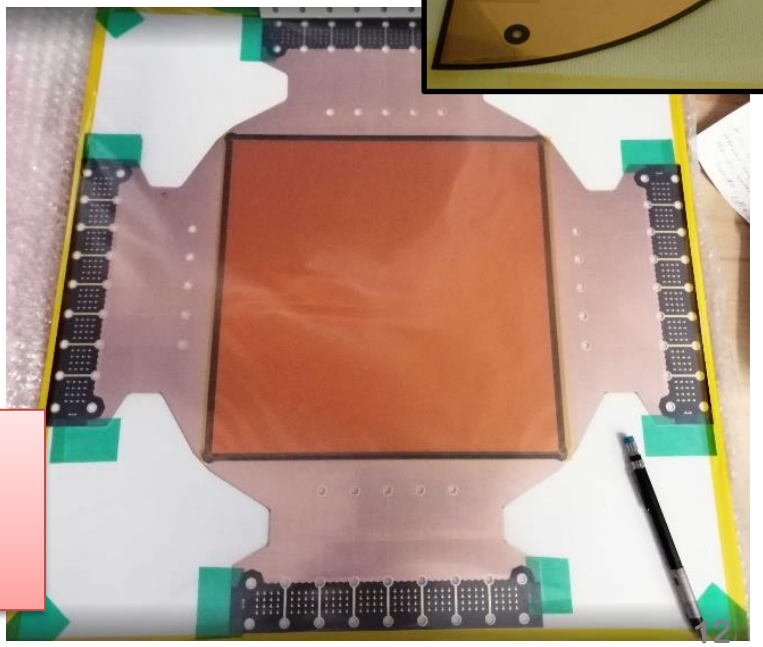




"Microbulk" Micromegas
Thanks to Rui's workshop at CERN !



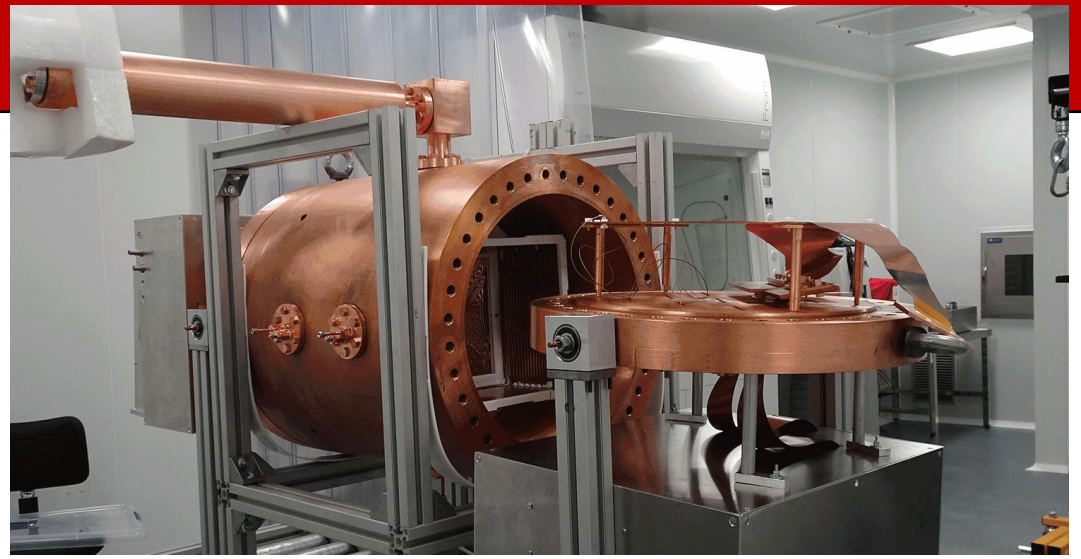




25 cm side
Largest
microbulk
up to now

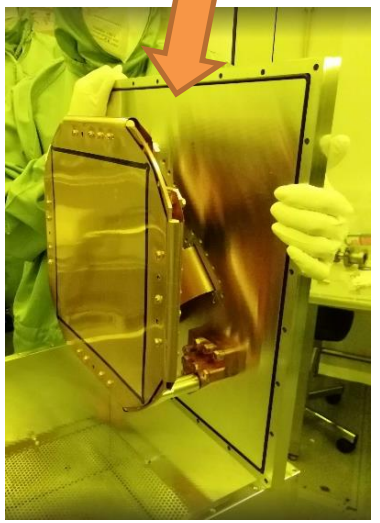
https://github.com/rest-for-physics

TREX-DM

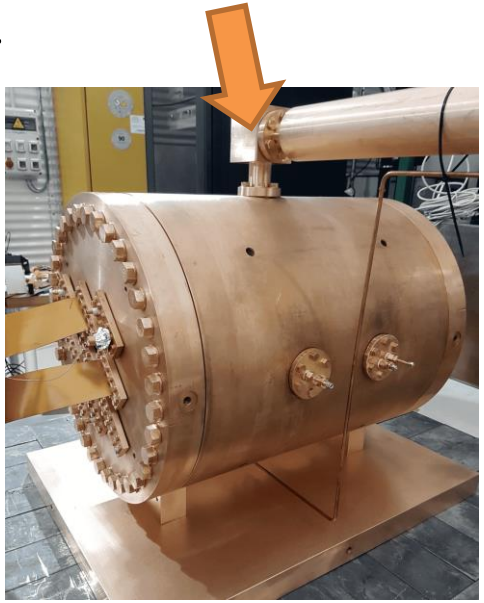


- Looking for DM at the low mass frontier
- Technology: very similar to CAST/IAXO focal detectors but 1000x larger size
- Very complementary with other technologies in the low-mass WIMP search
- Experiment status: under commissioning at LSC
- Targets:
  - <1 keV threshold (R&D to push it to <100 eV)
  - 1 dru background

Largest single unit microbulk MM ever built



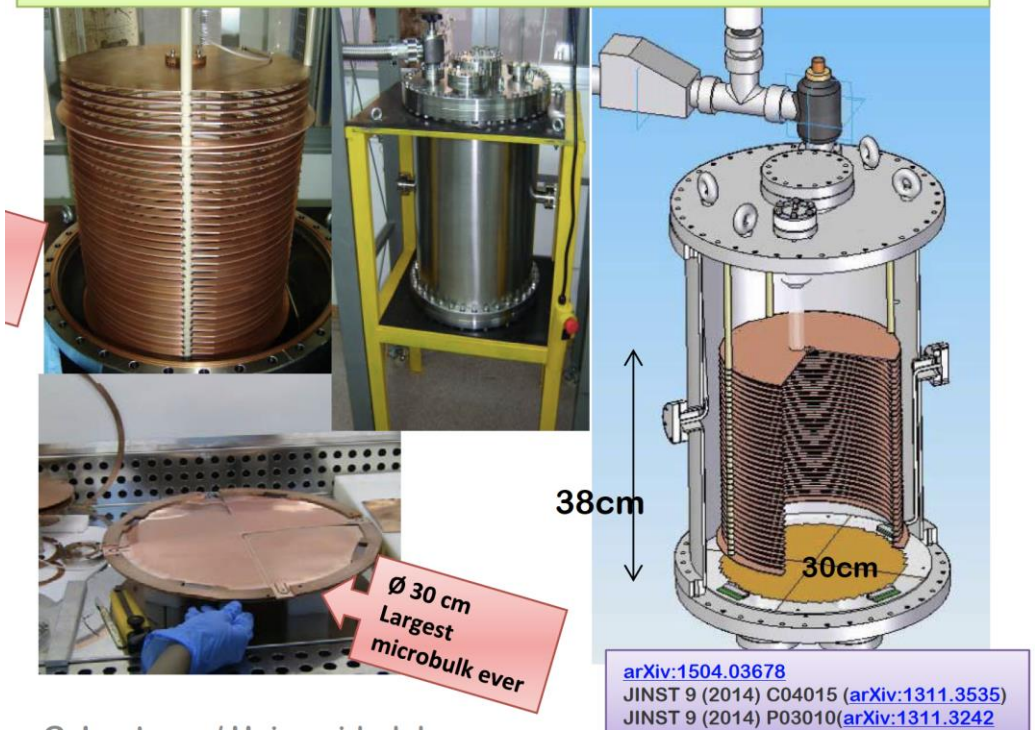
70L HP Neon TPC



MM for double beta decay?

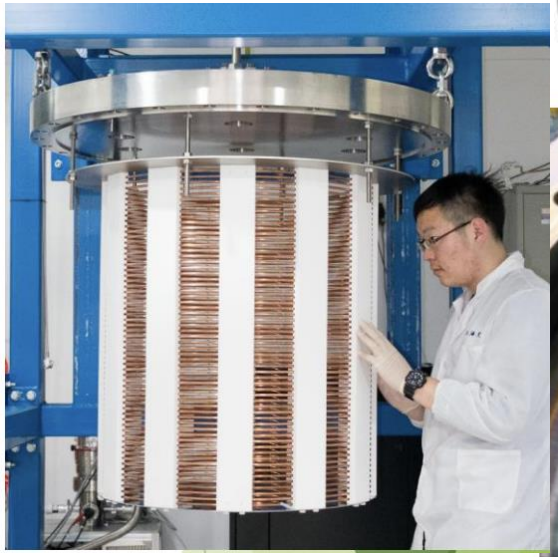
TREX-ββ-1 / NEXT-MM-1

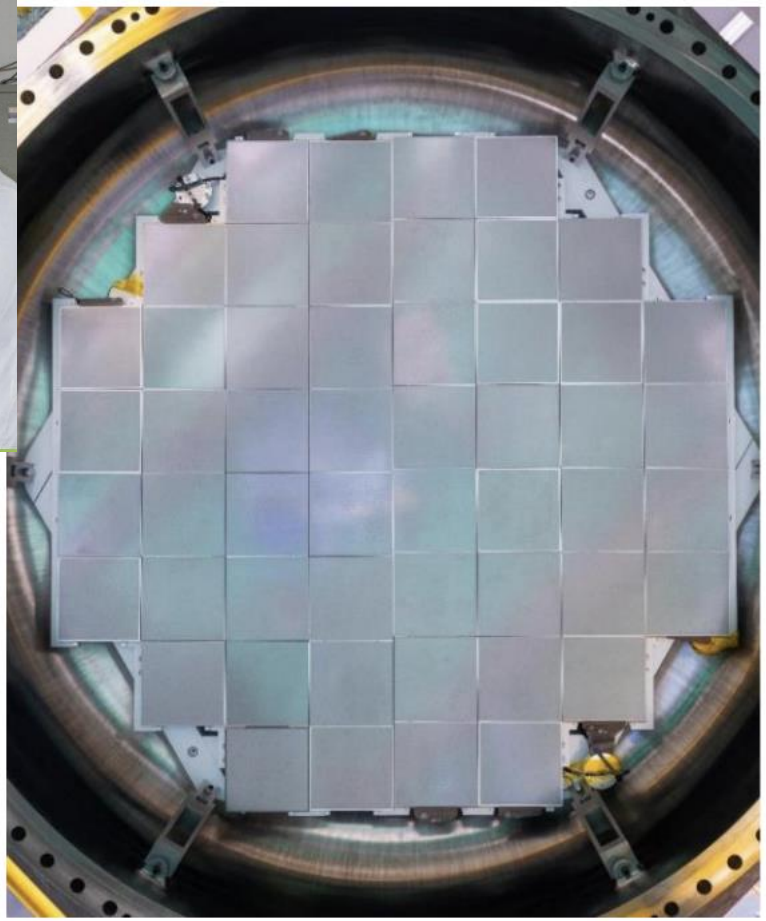
- Mid-size: 1 kg Xe fiducial
- Long e-tracks contained
- Fully equiped pixellized readout
  - (1200 channels – AFTER DAQ)
- Originally developed as tech demostrator for NEXT…



arXiv:1504.03678
JINST 9 (2014) C04015 (arXiv:1311.3535)
JINST 9 (2014) P03010(arXiv:1311.3242

PANDA X -III
PARTICLE AND ASTROPHYSICAL XENON TPC

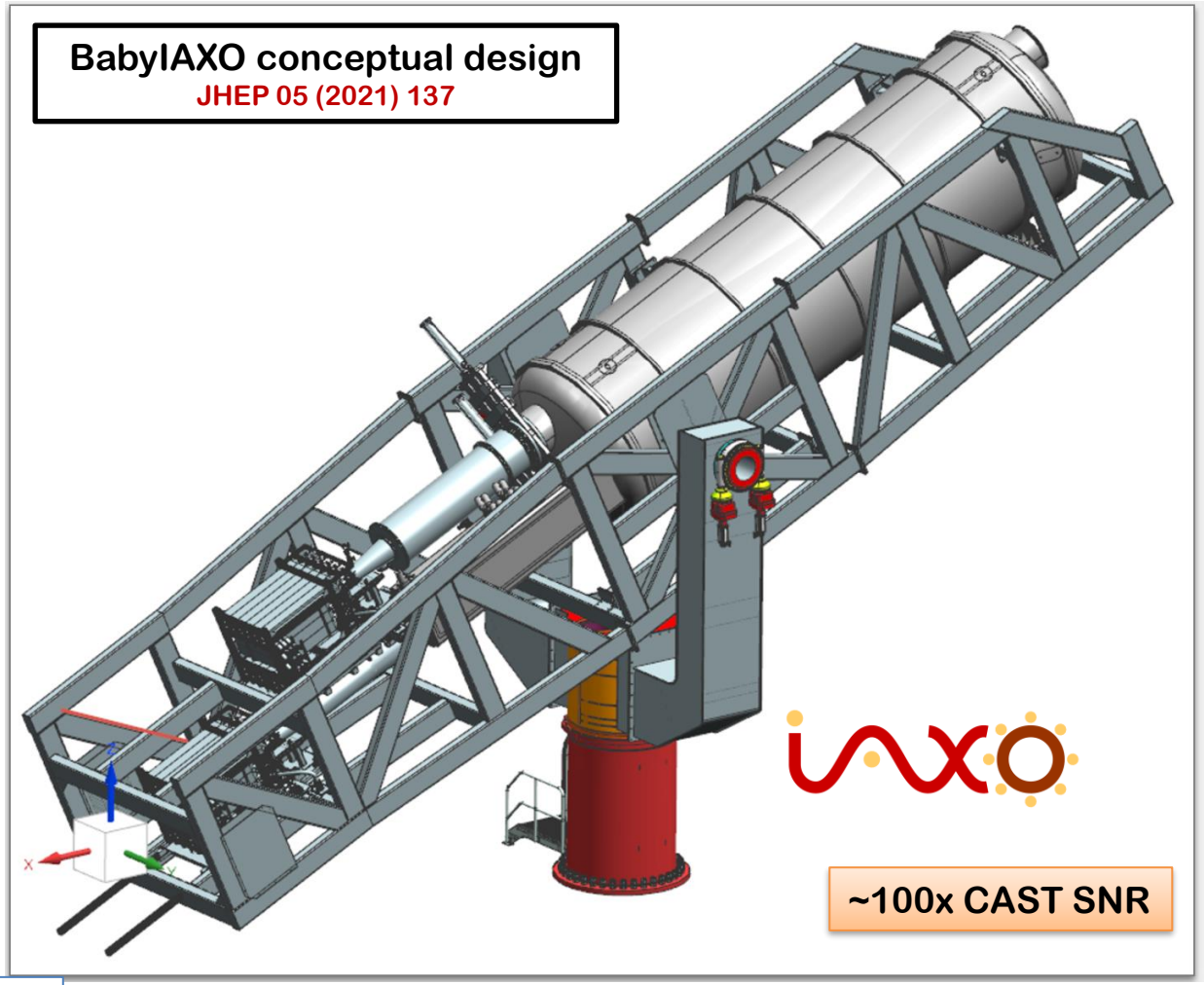




BabyIAXO

- **Prototype:** Intermediate experimental stage before IAXO
  - Two bores of dimensions similar to final IAXO bores → detection lines representative of final ones.
  - Magnet will test design options of final IAXO magnet
  - Test & improve all systems. Risk mitigation for full IAXO
- **Physics:** will also produce relevant physics outcome

  (~100 times larger FOM than CAST)

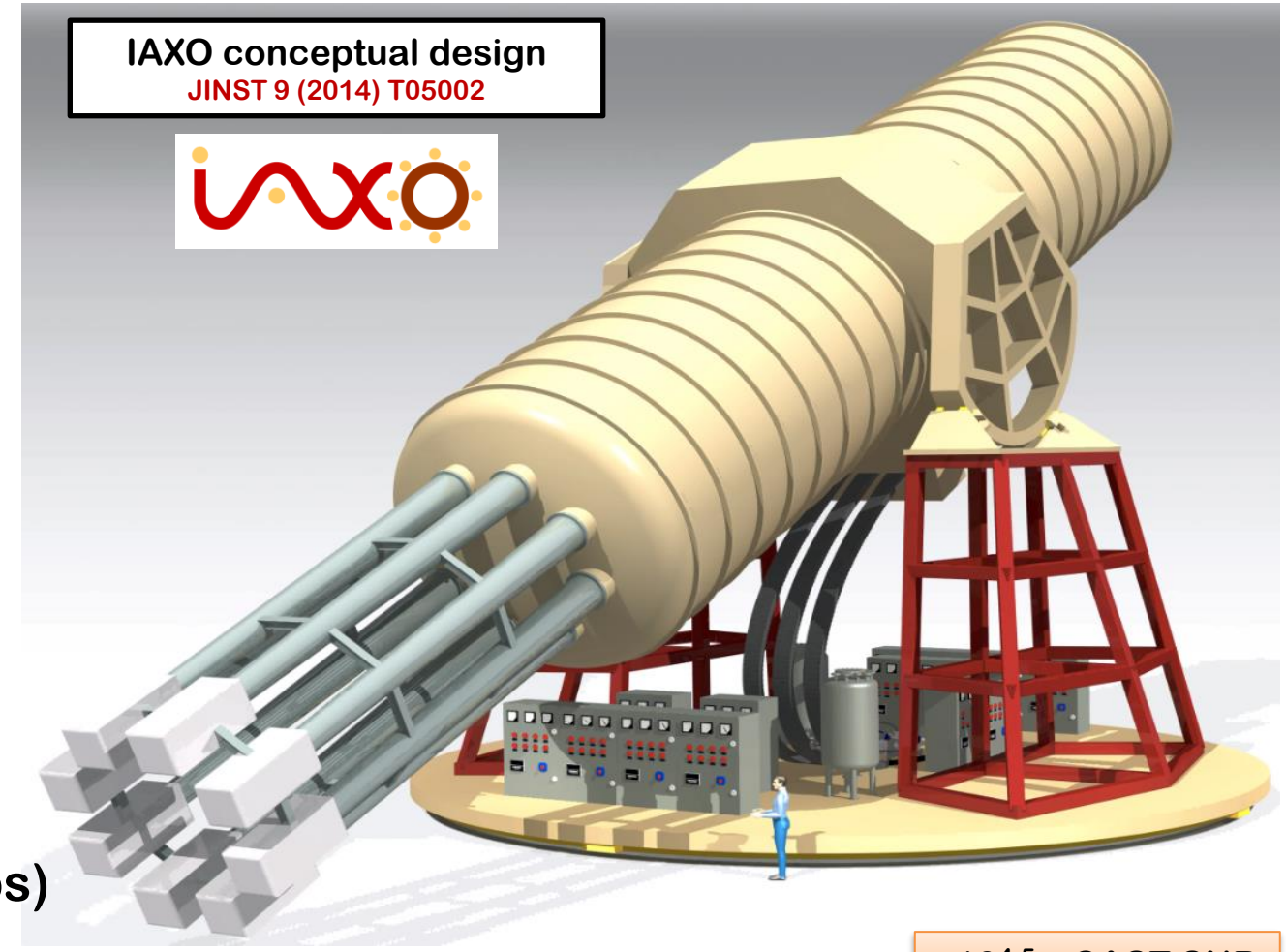


European Research Council
Established by the European Commission

ERC-AvG 2017 IAXO+

IAXO experiment summary

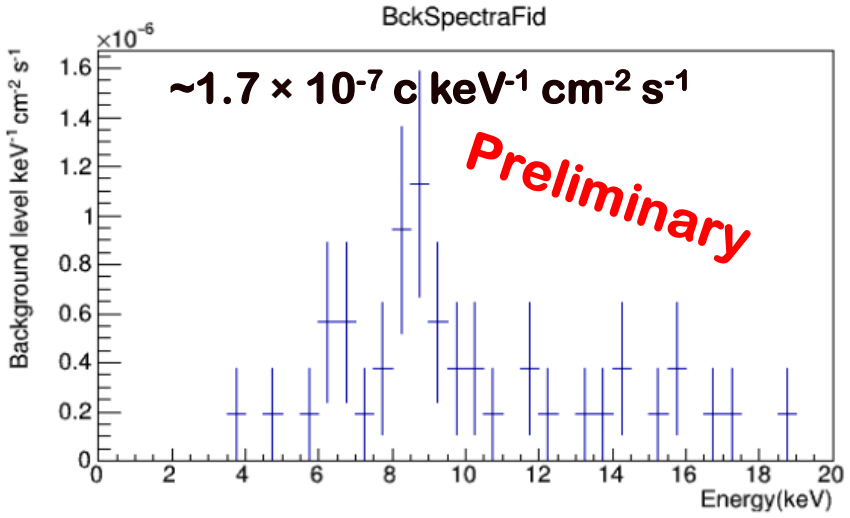
- Next generation “axion helioscope” after CAST
- Purpose-built large-scale magnet
  - >300 times larger B^2L^2A than CAST magnet
  - Toroid geometry
  - 8 conversion bores of 60 cm Ø, ~20 m long
- Detection systems (XRT+detectors)
  - Scaled-up versions based on experience in CAST
  - Low-background techniques for detectors
  - Optics based on slumped-glass technique used in NuStar
- ~50% Sun-tracking time
- Large magnetic volume available for additional “axion” physics (e.g. DM setups)



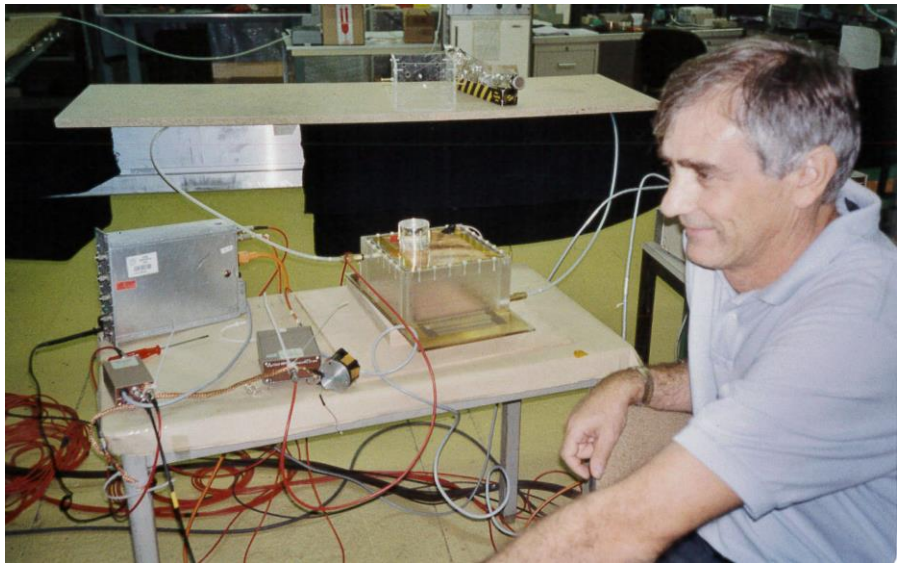
~$10^{4\text{-}5}$ x CAST SNR

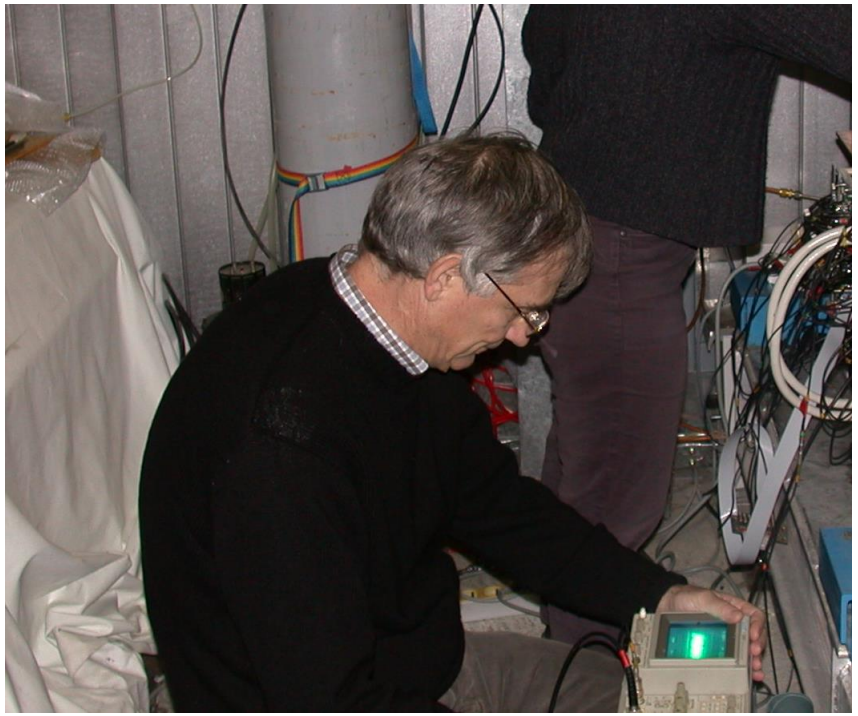
…and the saga continues

- **BabyIAXO detector prototypes. One of them underground now taking data at LSC**
- **First background results from Micromegas:**
  - **IAXO-D0 (Xe, surface, neutron shield): 8-9 × 10^{-7} c keV^{-1} cm^{-2} s^{-1}**
  - **IAXO-D1 (Ar, underground LSC): 1.7 × 10^{-7} c keV^{-1} cm^{-2} s^{-1}**



- Ioannis pioneering efforts with Micromegas have had a long-standing impact in the Rare Event field…





But equally important is his personal impact of his kindness, closeness, and support as a colleague, mentor and friend