Quantum Detectors for particle physics

(focus on applying quantum sensors to HEP,
in addition to low energy particle physics)

M. Doser
Oxford University



Focus on detectors!

1. Clarification of terms
2. Some words on the landscape
3. Quantum sensors for particle physics
4. "DRD5"

quantum sensors register a change of quantum state caused by the interaction with an external system:

- transition between superconducting and normal-conducting
- transition of an atom from one state to another
- change of resonant frequency of a system (quantized)

} highly sensitive and highly specific sensors for minute perturbations of the environment in which they operate

bottom line: quantum sensors measure result of *a single* individual interaction

Then, a "quantum sensor" is a device, the measurement (sensing) capabilities of which are enabled by our ability to manipulate and read out its quantum states.

and because the commensurate energies are very low, unsurprisingly, quantum sensors are ideally matched to low energy (particle) physics;

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for this workshop, however, focus mainly on activities in high energy particle physics

(I will *not* however be talking about entanglement and its potential for *detectors*)

2 Quantum sensors for high energy physics

given that most detectors rely on detecting the product of many inter-actions between a particle and the detector (ionization, scintillation, Čerenkov photons, …), this is not obvious

Quantum Technology → Technical application

Investigate & build on Quantum engineering

Piggyback off rapid advances in other fields

Think about "(quantum) pump & (classical) probe"

Federate efforts among institutions and fields

ECFA roadmap

National quantum initiatives

Put semantics aside: handful of ideas that rely on quantum devices, or are inspired by them. Not necessarily used as quantum detectors per se, but rather their properties to enhance / permit measurements that are more difficult to achieve otherwise → Frontiers of Physics, M. Doser et al., 2022 doi: 10.3389/fphy.2022.887738

2

ECFA Detector R&D Roadmap: *Quantum and Emerging Technologies*

→ https://indico.cern.ch/event/999818/
→ https://indico.cern.ch/event/957057/page/23281-the-roadmap-document

→ Detector R&D Collaboration (DRD5): WP-1 - WP-6

domains of physics

- search for NP / BSM
- Axions, ALP's, DM & non-DM UL-particle searches
- tests of QM — wavefunction collapse, decoherence
- EDM searches & tests of fundamental symmetries

Development of new detectors

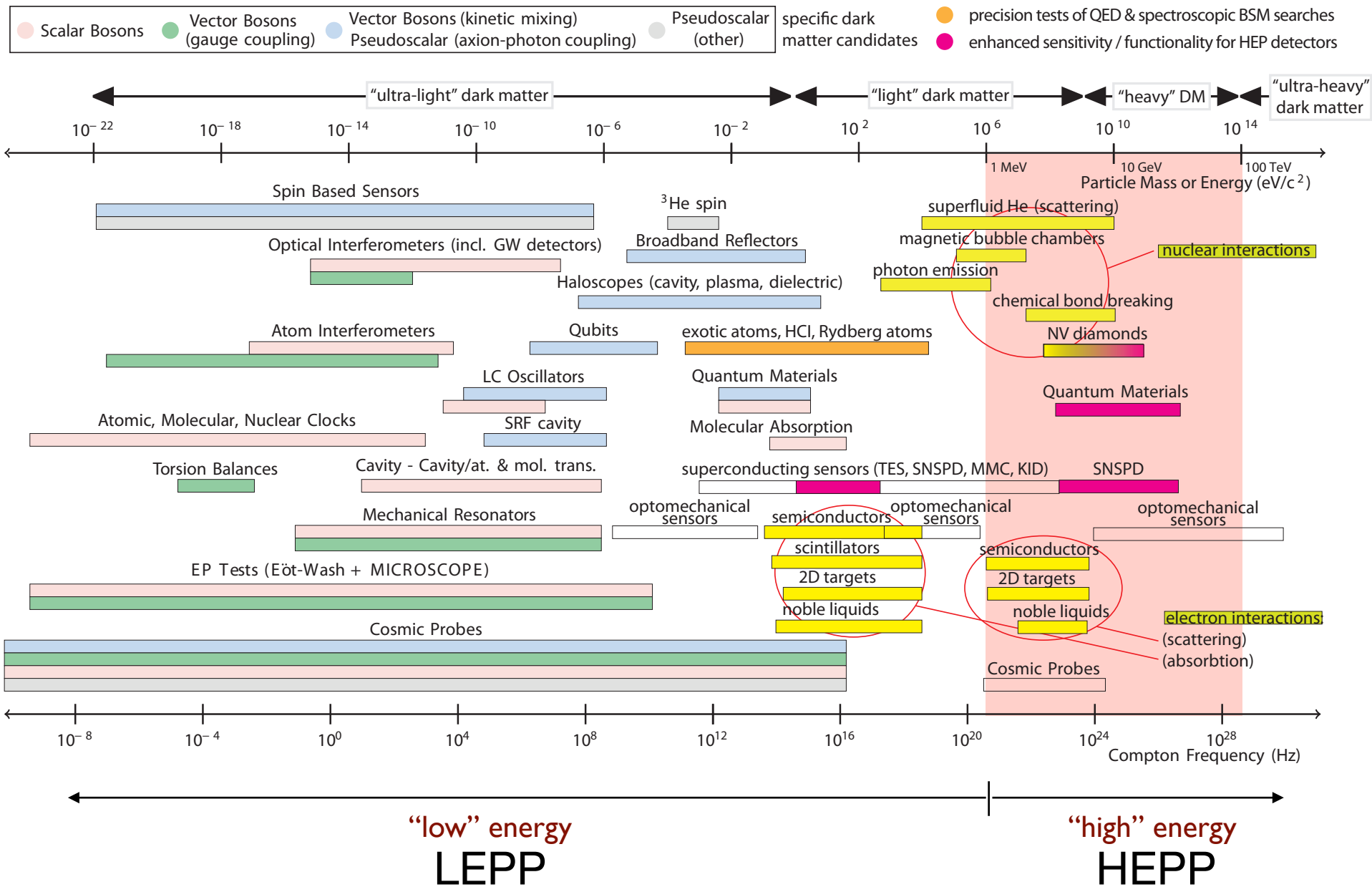
roadmap quantum technologies

1. superconducting devices (TES, SNSPD, …) / cryo-electronics — WP-3
2. spin-based, NV-diamonds — WP-4
3. optical clocks — WP-1
4. ionic / atomic / molecular — WP-1
5. optomechanical sensors — WP-5
6. metamaterials, 0/1/2-D materials — WP-2

Qbit-relevant technologies

"Quantum" is everywhere

Landscape: quantum sensing applied to an extremely wide range of DM searches



3 Quantum sensors for high energy physics



these are not fully developed concepts, but rather the kind of approaches one might contemplate working towards

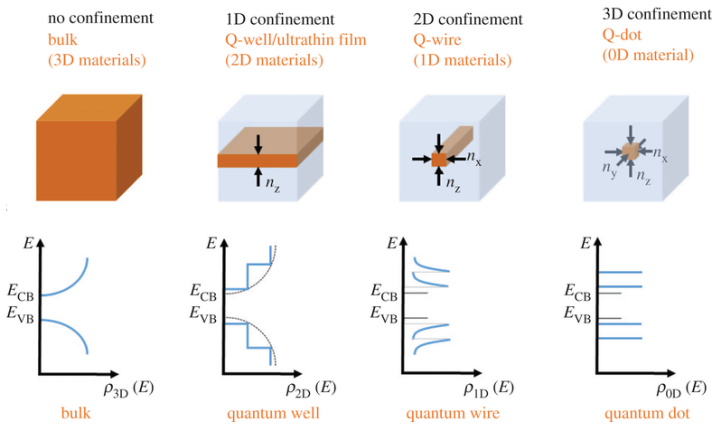
Mostly speculative!

Quantum Technology		Technical application	
Metamaterials, 0 / 1 / 2-dimensional materials	WP-2	chromatic calorimetry (QDs) fs timing layers (PID)	QTI@CERN
Atoms, molecules, ions	WP-1	Rydberg TPC	
Spin-based sensors	WP-4	helicity detectors	
Superconducting sensors	WP-3	cryogenic ps luminosity monitors	QTI@CERN

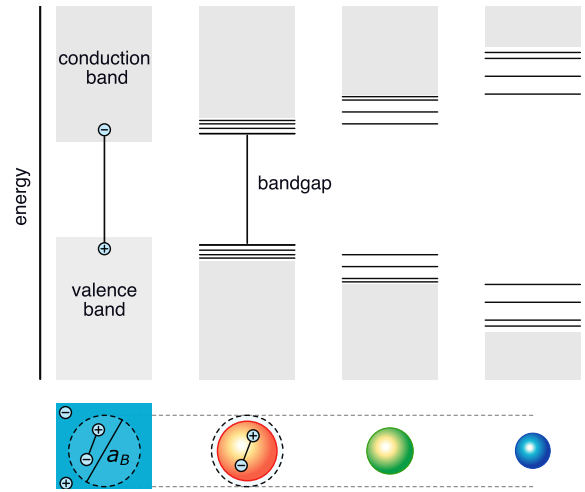
3 Quantum dots:

timing & chromatic tunability

Dimensional quantum confinement

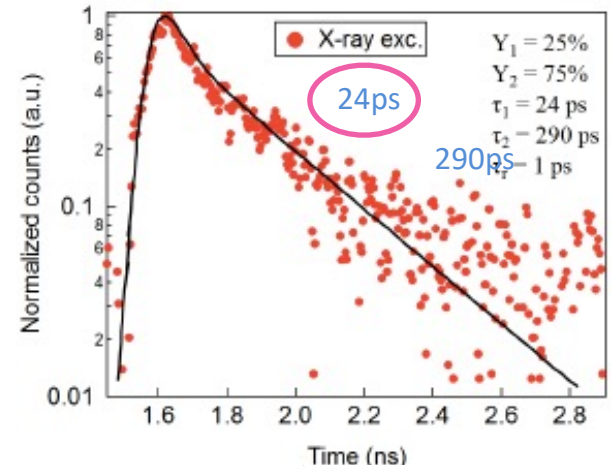


QD size (~ 2-10 nm)



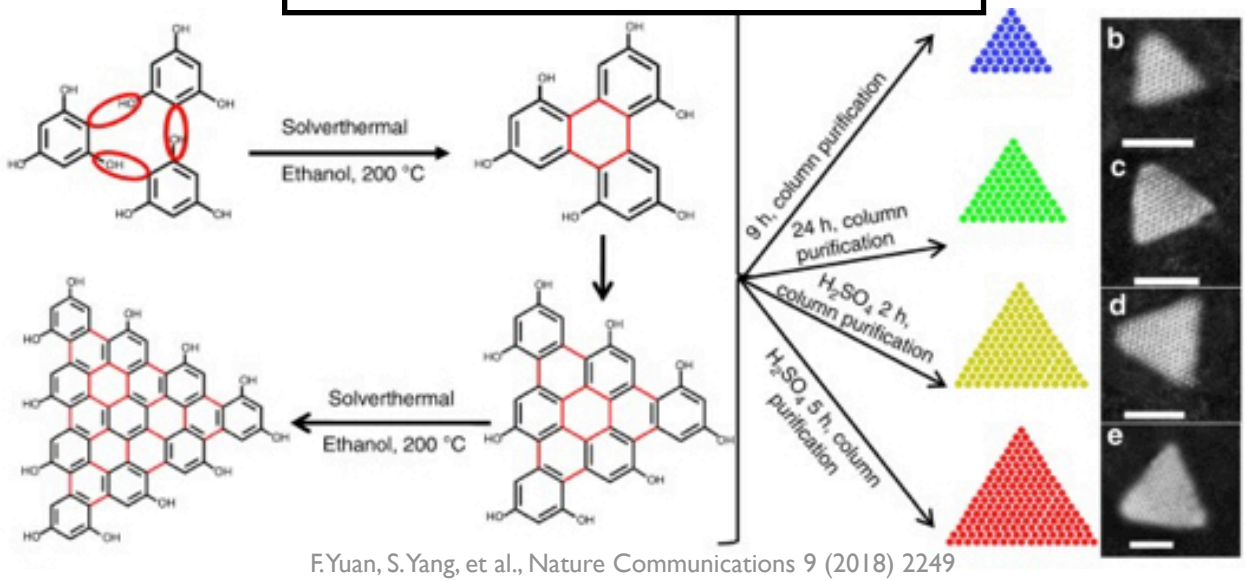
Goyal, R.K., Maharaj, S., Kumar, P. *et al.* Exploring quantum materials and applications: a review. *J Mater. Sci: Mater Eng.* **20**, 4 (2025). https://doi.org/10.1186/s40712-024-00202-7

CdSe nanoplatelet



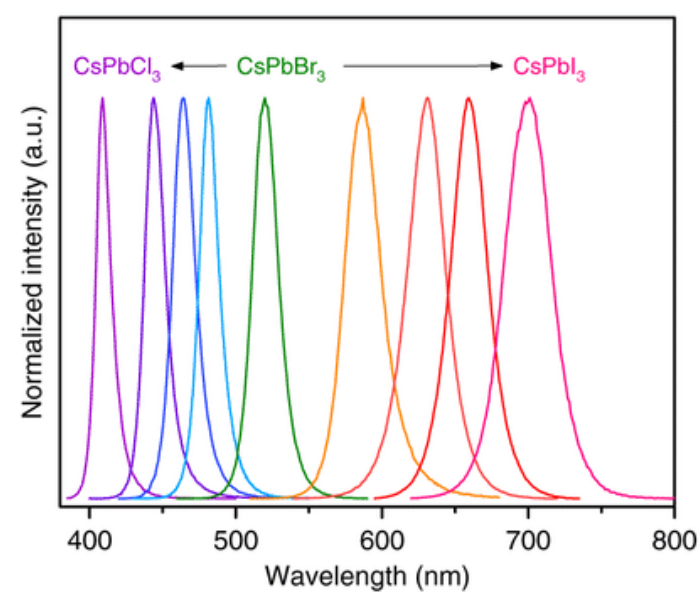
J. Grim et al., Nature Nanotechnology, 9, 2014, 891-895
R. Martinez Turtos et al., 2016 JINST_11 (10) P10015

e.g. triangular carbon nanodots



F.Yuan, S.Yang, et al., Nature Communications 9 (2018) 2249

by size, composition, geometry



3 Quantum dots: chromatic calorimetry

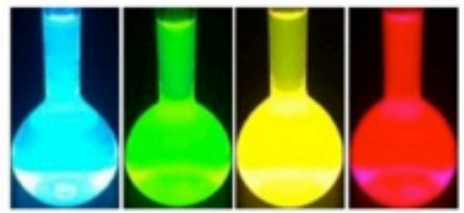
absorption spectrum

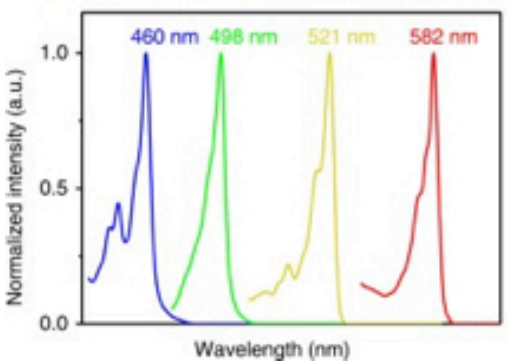


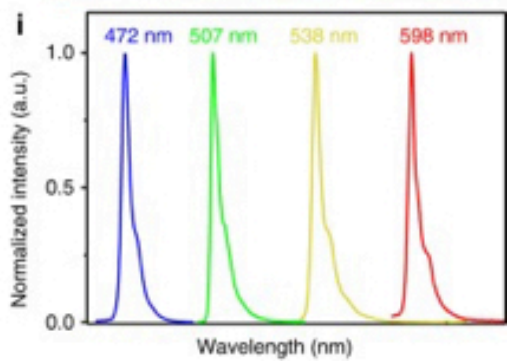
λ_{ex}: 365 nm

UV illumi-nation

emission spectrum





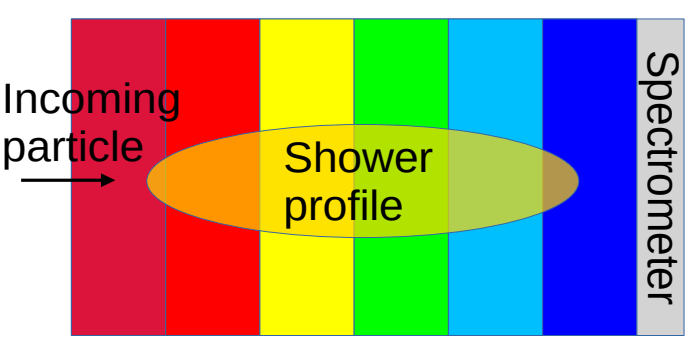


e.m. shower

Narrowband emission: large Stokes shift

e.g. absorb wavelengths < 585 nm
emit at > 595 nm

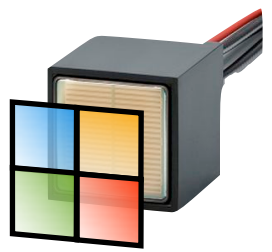
if high-Z substrate transparent in 400-700 nm, then no re-absorption of emitted light



(shower profile via *spectrometry*)

Optical filters

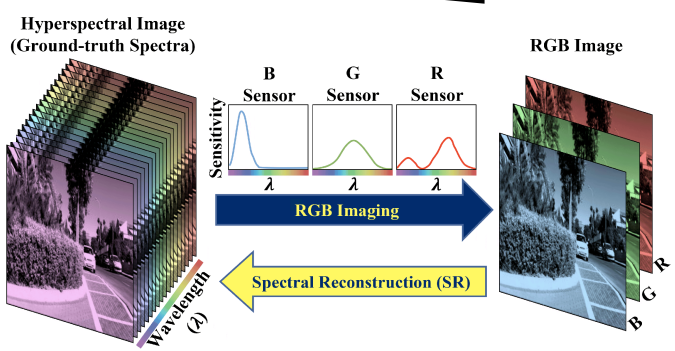
Inefficient; angular acceptance…



Pixel-based reconstruction

RGB-based photodetectors, requires advanced algorithms to extract spectrum from RGB values

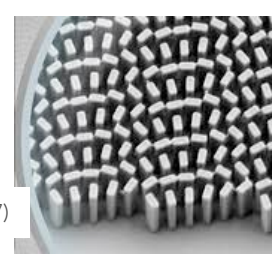
Y.T. Lin & G. Finlayson, *Sensors* 2023, *23*(8), 4155

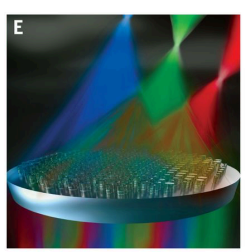


Metalenses

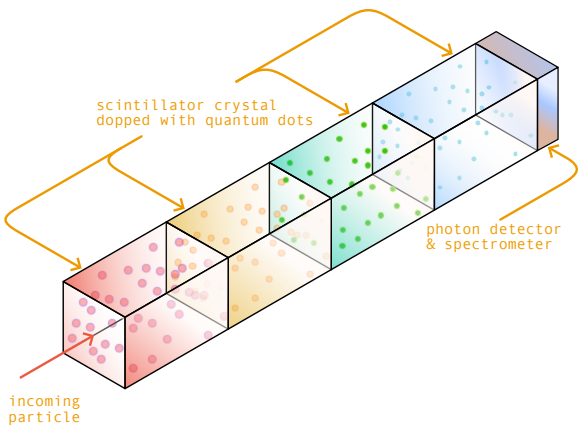
Compact, nanostructured optical devices for precise light focusing. Requires further development for scalability in HEP.

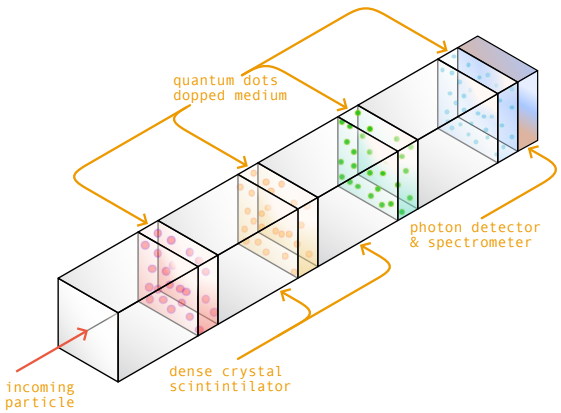
R. Cheng, M. Khorasaninejad & F. Capasso, Science 358, 6367 (2017)



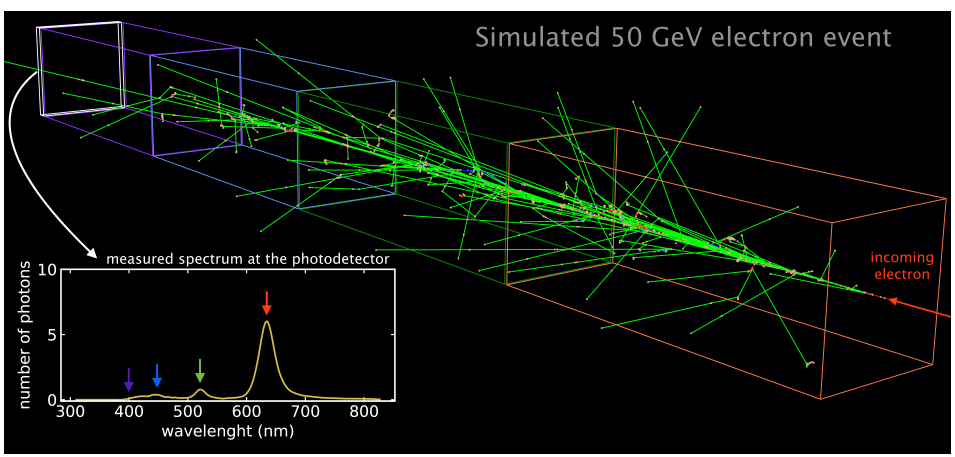


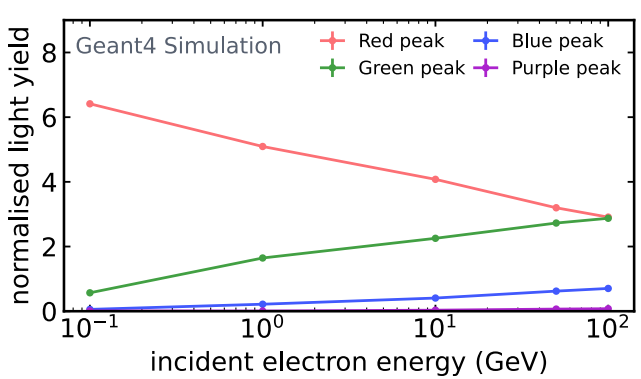
3 This slide courtesy Devanshi Arora, CALOR'24





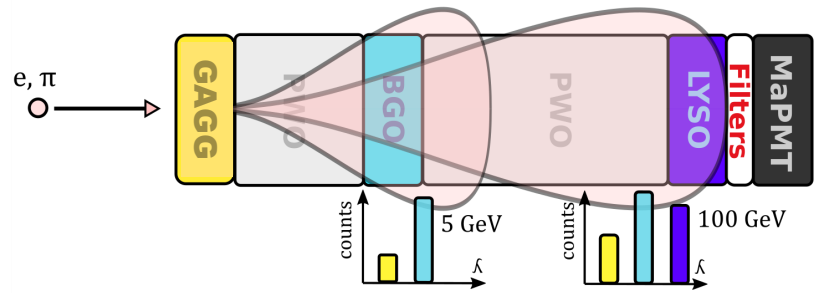
courtesy Y. Haddad, N U, Boston, USA





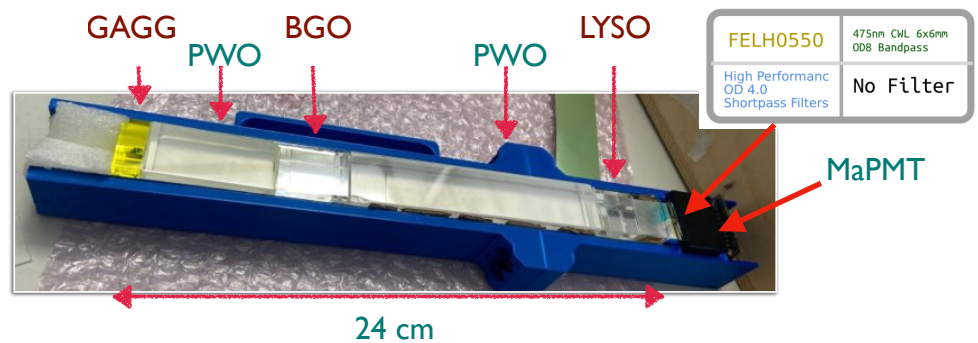
"Chromatic" energy measurement

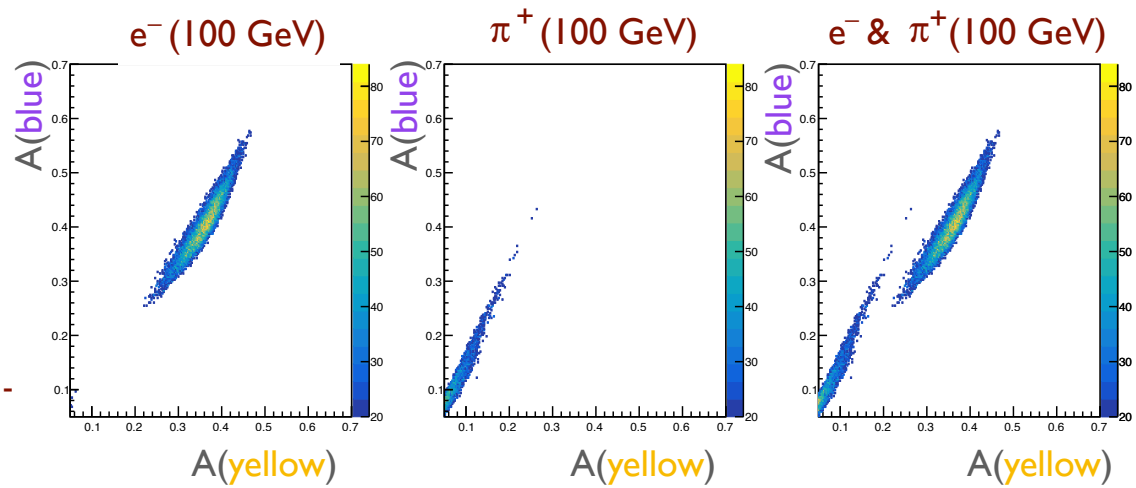
"Chromatic" electron - pion discrimination



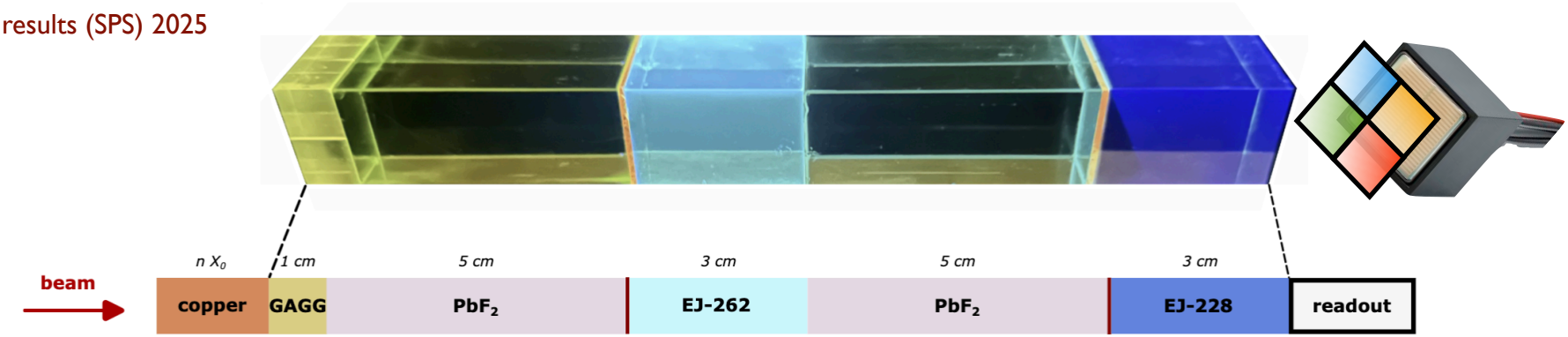
Beam test results (SPS) 2023

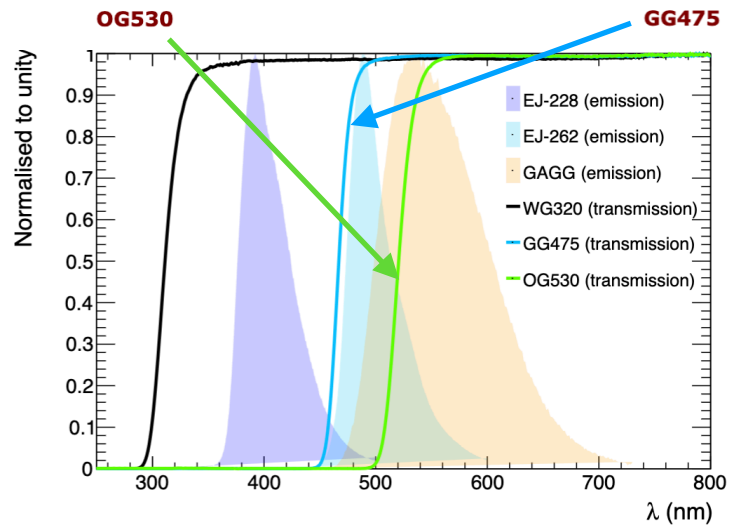
Light filters





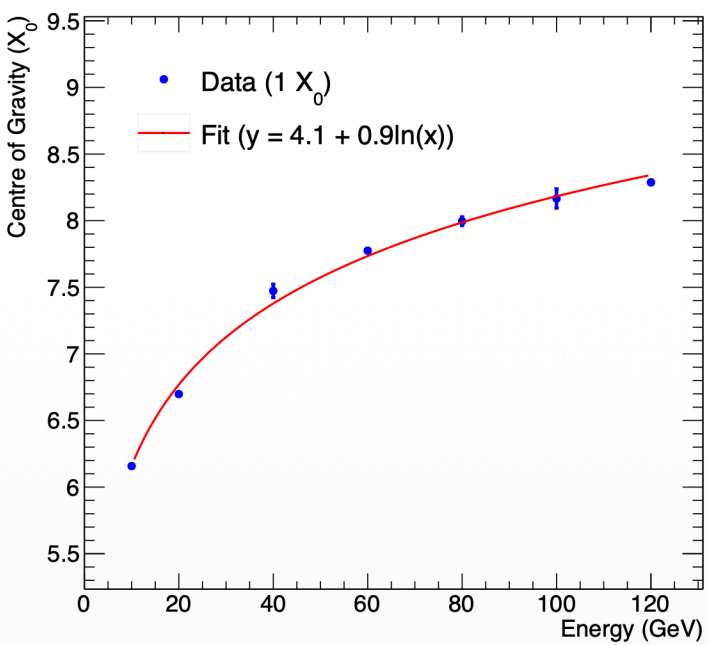
86% "chromatic" electron - pion discrimination





CCAL can resolve the longitudinal shower profile

PID through rel. intensities confirmed



Low-pass filter (blue/green)
Low-pass filter (red/yellow)

Proof-of-principle Geant4 simulations show that CCAL achieves a linear energy response and energy resolution comparable to benchmarks such as the CMS ECAL, with the added advantage of depth segmentation.

Nanocomposites are effective wavelength shifters for chromatic calorimetry, but further studies are needed to use them as scintillators.

Improving energy transfer between ionisation and light emission in polymers/QDs needs further work

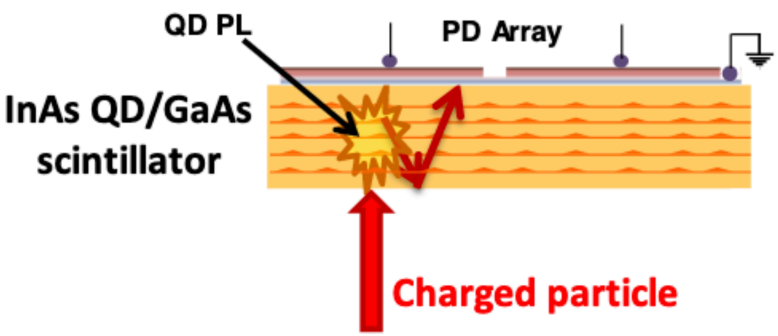
3 Quantum dots: chromatic tracking

- Quantum dots in CMOS pixels: DoTPiX

  n-channel MOS transistor + buried quantum well gate (Ge layer deposited on silicon substrate); gate collects holes, modulates current

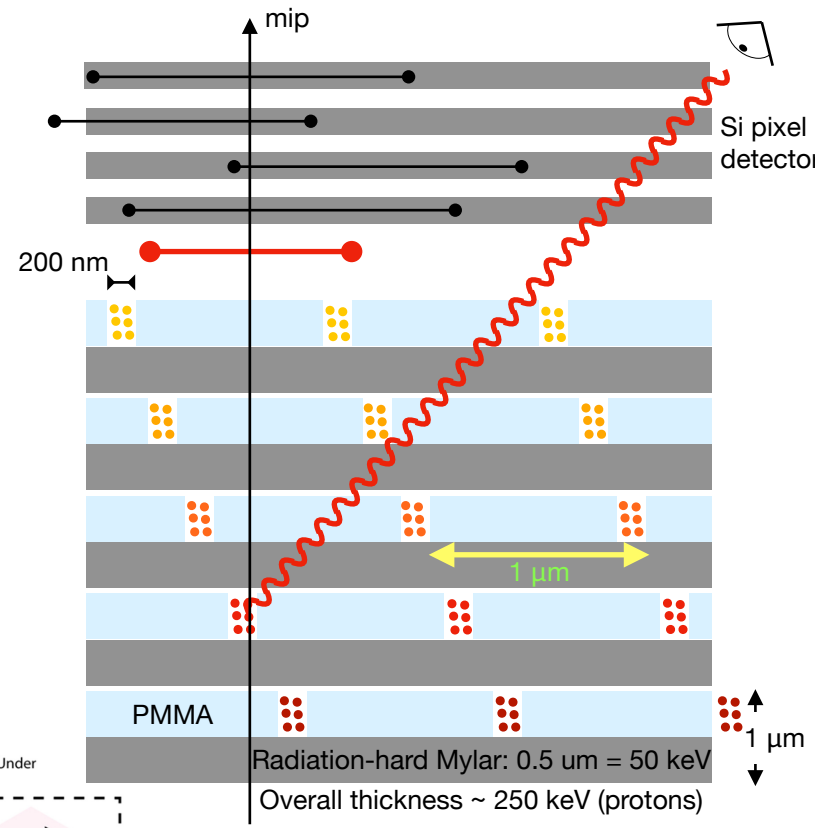
- GaAs scintillator / InAs Quantum dots + PD

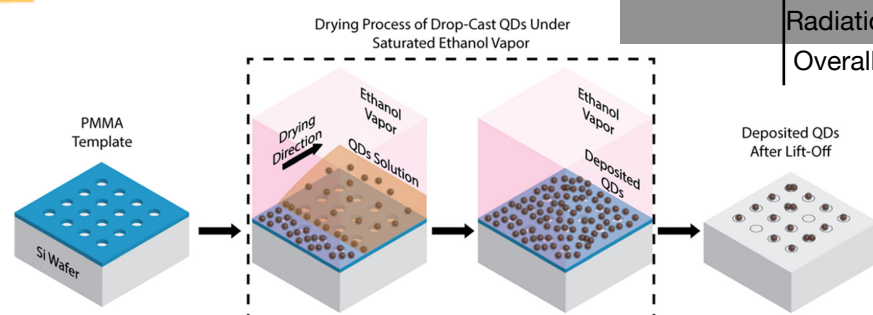
  GaAs bulk generates e/h pairs, InAs QD's trap charge; dots emit photons via photoluminescence, collected by proximate photodiode



[Maximov et al., Appl. Sci. 2020, 10, 1038;
M.Hoeferkamp et al., arXiv:2202.11828;
A. Minns et al., MRS Advances 6, 297–302 (2021)]

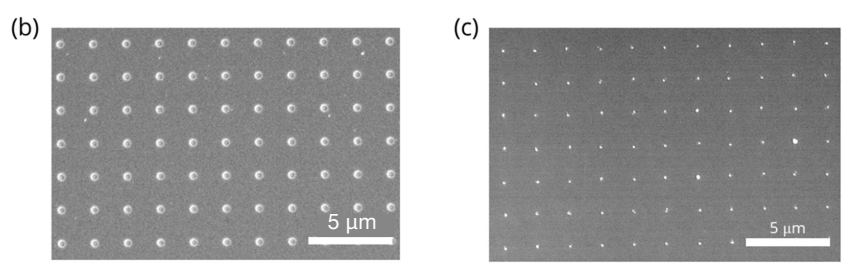
- IR Quantum dots in periodic wells in thin layers





Assembly positioning to < 100 nm

https://xeryon.com/products/precision-linear-stages/xls-ultrasonic-linear-piezo-stage/



Nanoscale, 2024, 16, 18339
https://ds.bilkent.edu.tr/wp-content/uploads/2024/10/Nanoscale1_2024_HVD.pdf

3 Thin layers: (optical) charged particle detection (10 μm ~ 30 fs; mip ~ 2 keV)

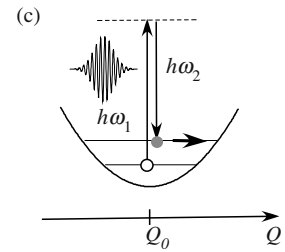
3.6 eV of energy creates one e/h pair in silicon ~ 50-100 pairs

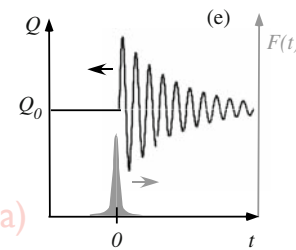
The difference of this energy to the band gap energy of silicon (≈1.12 eV at room temperature) is dispersed as phonons.

Particle-energy-loss triggered coherent lattice oscillations (Initiated by Georgy Kornakov)

coherent optical phonon spectroscopy (transient reflectivity and transmission measurements) has been a simple and powerful tool to probe femtosecond lattice dynamics

Ishioka, K., Misochko, O.V. (2010). Coherent Lattice Oscillations in Solids and Their Optical Control. In: Yamanouchi, K., Giulietti, A., Ledingham, K. (eds) Progress in Ultrafast Intense Laser Science. Springer Series in Chemical Physics, vol 98. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-03825-9_2

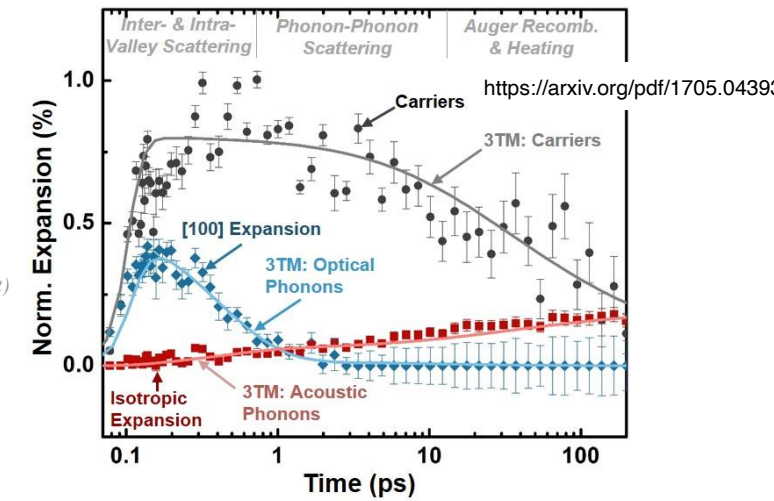




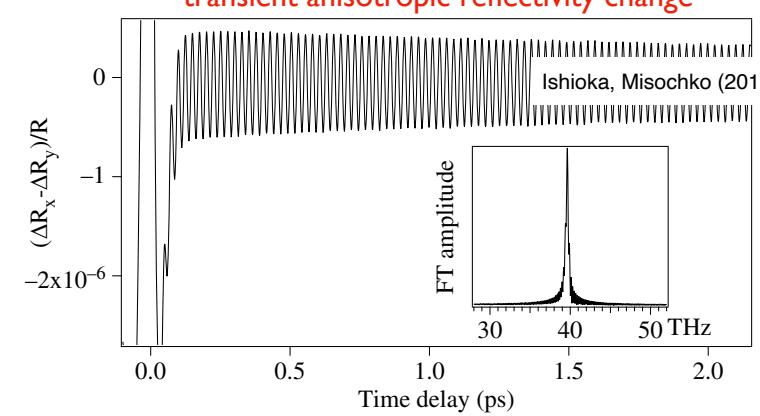
Particle-induced frequency shifts in optical resonators (Initiated by Anastasia Kotsokechagia)

Particle-induced magnetic avalanches in SMMs (Initiated by P. Bunting, G. Gratta, T, Melia, S. Rajendran)

Time-dependent lattice deformation of 0.1-0.3% expansion



transient anisotropic reflectivity change



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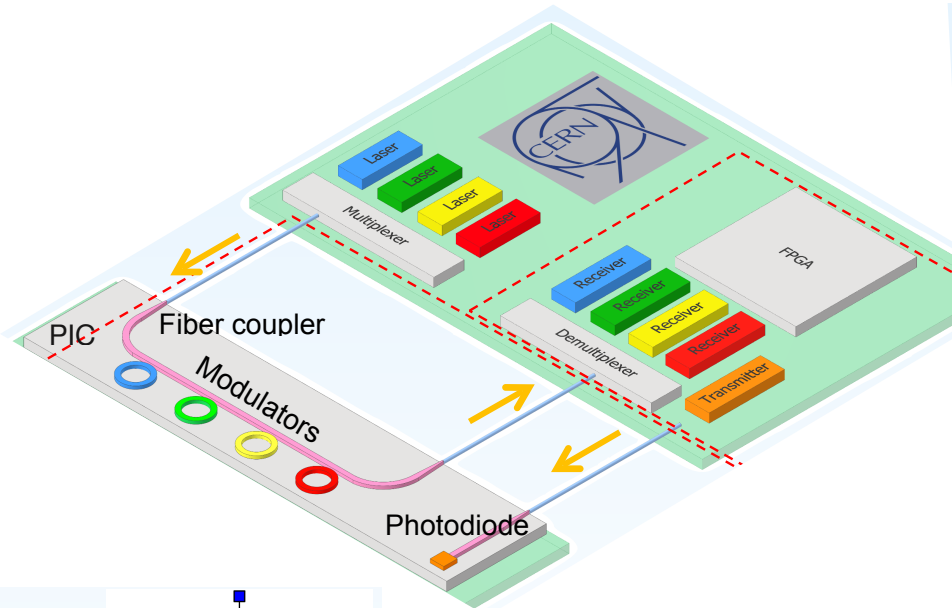
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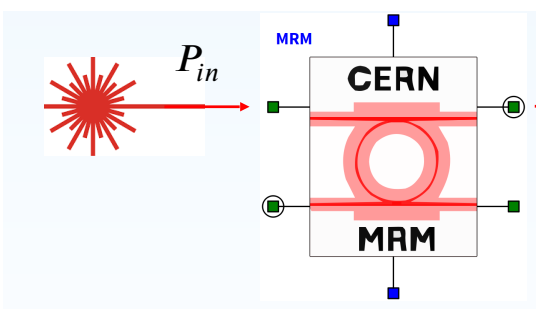
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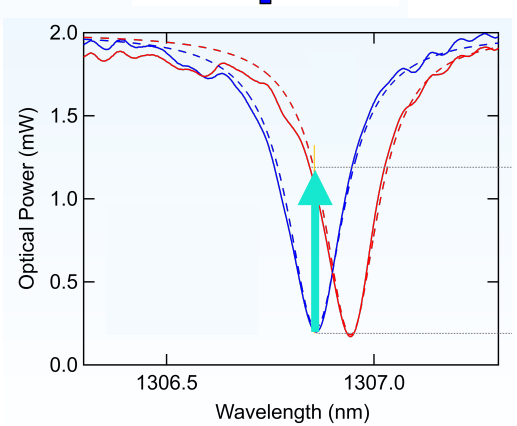
Ishioka, K., Misochko, O.V. (2010). Coherent Lattice Oscillations in Solids and Their Optical Control. In: Yamanouchi, K., Giulietti, A., Ledingham, K. (eds) Progress in Ultrafast Intense Laser Science. Springer Series in Chemical Physics, vol 98. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-03825-9_2

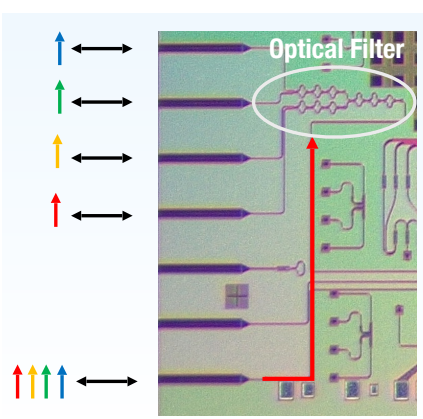


Particle-induced frequency shifts in optical resonators
(Initiated by Anastasia Kotsokechagia)

Micro-ring modulators as detectors:
shift in optical properties = (tiny) shift in resonant frequency
= (tiny) shift in coupled intensity
= receiver sees transient intensity drop







Particle-induced magnetic avalanches in SMMs
(Initiated by P. Bunting, G. Gratta, T, Melia, S. Rajendran)

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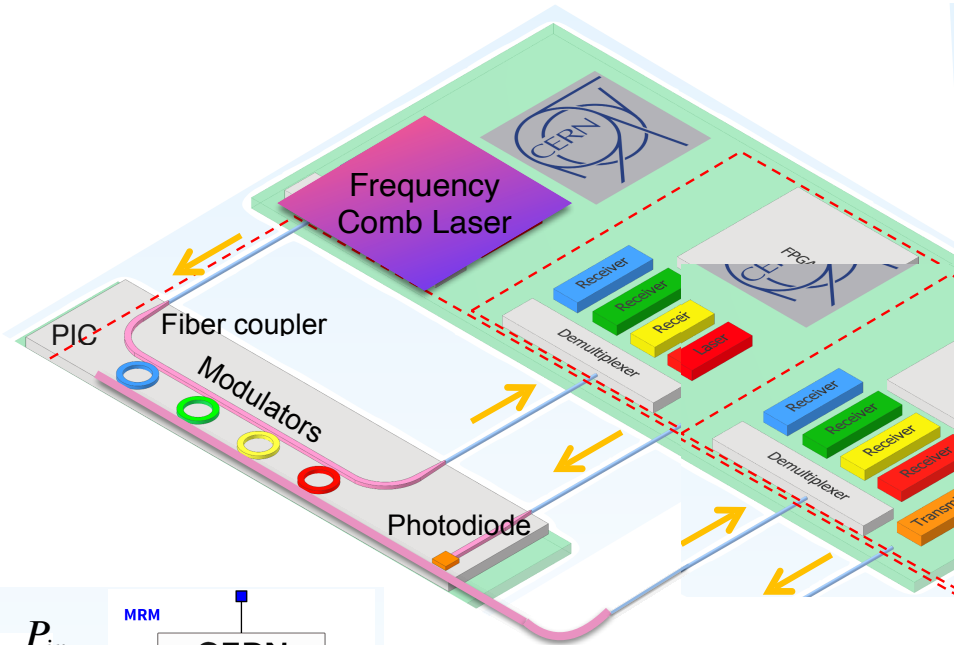
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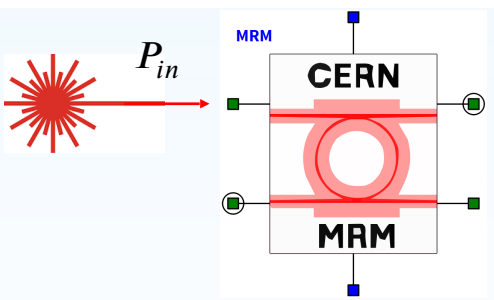
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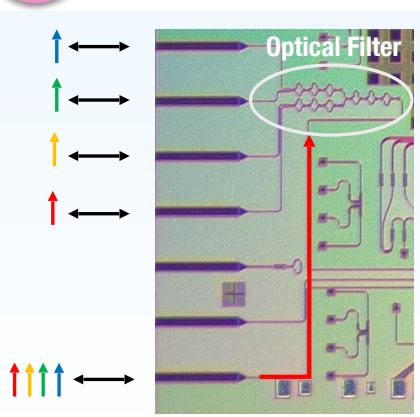
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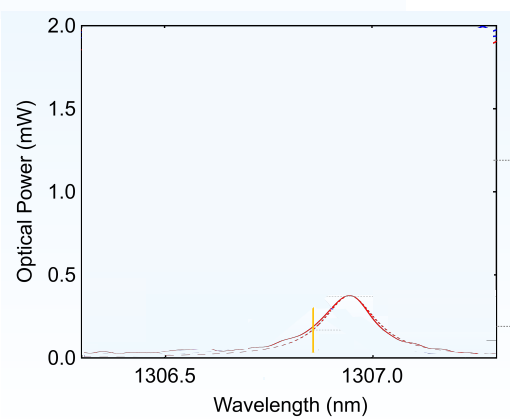
Micro-ring modulators as detectors:
shift in optical properties = (tiny) shift in resonant frequency
= (tiny) shift in coupled intensity
= receiver sees transient intensity drop
= coupling through MRM to 2nd fiber?

~ similar to TES array R/O via broadband RF









Particle-induced magnetic avalanches in SMMs
(Initiated by P. Bunting, G. Gratta, T, Melia, S. Rajendran)

3 Thin layers: (optical) charged particle detection (10 μm ~ 30 fs; mip ~ 2 keV)

3.6 eV of energy creates one e/h pair in silicon ~ 50-100 pairs

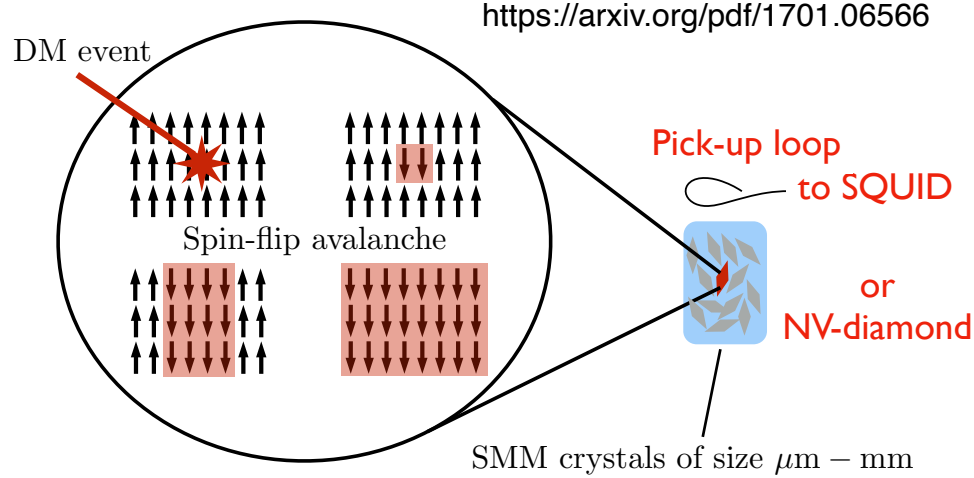
The difference of this energy to the band gap energy of silicon (≈1.12 eV at room temperature) is dispersed as phonons.

Particle-energy-loss triggered coherent lattice oscillations
(Initiated by Georgy Kornakov)

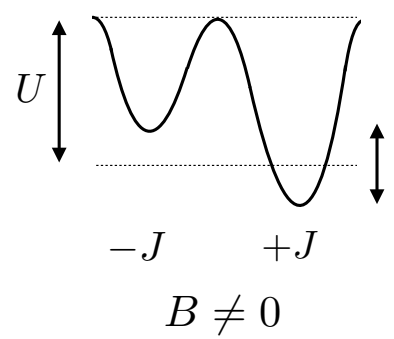
coherent optical phonon spectroscopy (transient reflectivity [9,10] and transmission [7] measurements) has been a simple and powerful tool to probe femtosecond lattice dynamics

Ishioka, K., Misochko, O.V. (2010). Coherent Lattice Oscillations in Solids and Their Optical Control. In: Yamanouchi, K., Giulietti, A., Ledingham, K. (eds) Progress in Ultrafast Intense Laser Science. Springer Series in Chemical Physics, vol 98. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-03825-9_2

https://arxiv.org/pdf/1701.06566



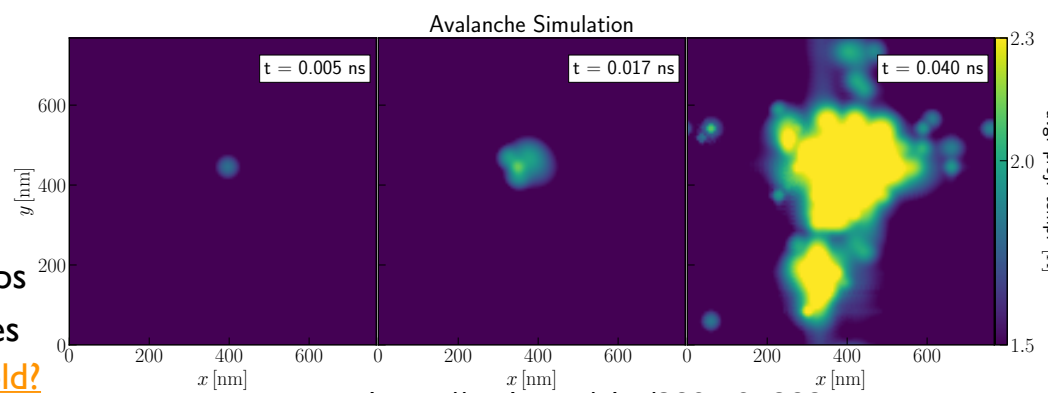
Particle-induced frequency shifts in optical resonators
(Initiated by Anastasia Kotsokechagia)



1. cool the system to temperatures ~0.1 K
2. apply a magnetic field (~0.1−1 T)
3. 50 / 50 stable / meta-stable population

(Very long magnetic relaxation times at low temperature)

Particle-induced magnetic avalanches in Single Molecule Magnets
(Initiated by P. Bunting, G. Gratta, T, Melia, S. Rajendran)



https://arxiv.org/abs/2607.01868v1

SMM's are tiny, essentially non-interacting magnets

SMM's are easily and cheaply synthesized

SMM's exist in fluorescent versions

Avalanche is fast: local magnetic relaxation time can drop below ~10 ps

Reset of detector is slow… better suited to DM, beam dump searches

or operation in ~MHz oscillating magnetic field?

Metamaterials, 0 / 1 / 2-dimensional materials (quantum dots, nanolayers)

- ultra-fast scintillators based on perovskytes
- chromatic calorimetry (QDs)
- active scintillators (QCL, QWs, QDs)
- GEMs (graphene)

Atoms, molecules, ions

- Rydberg TPC's

Spin-based sensors

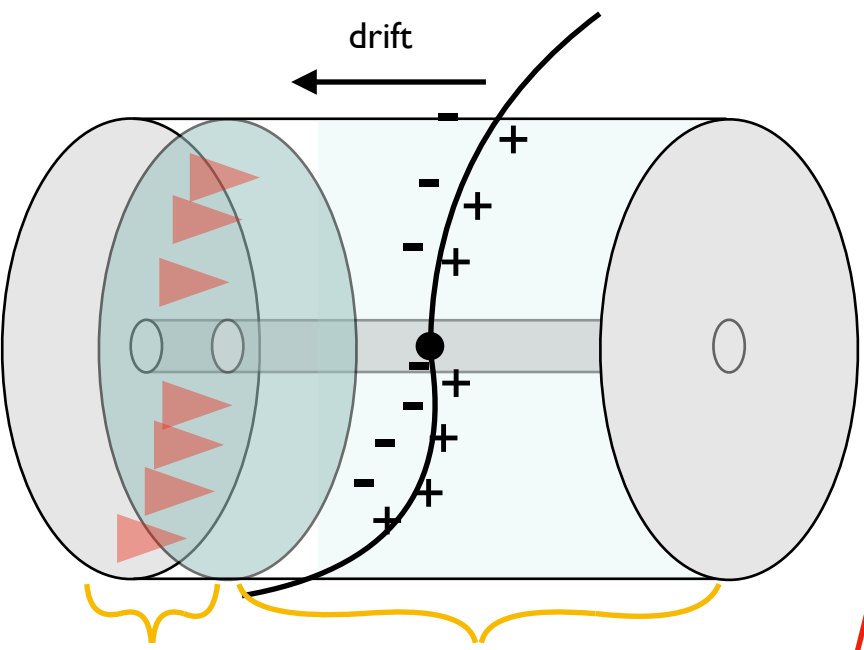
- helicity detectors

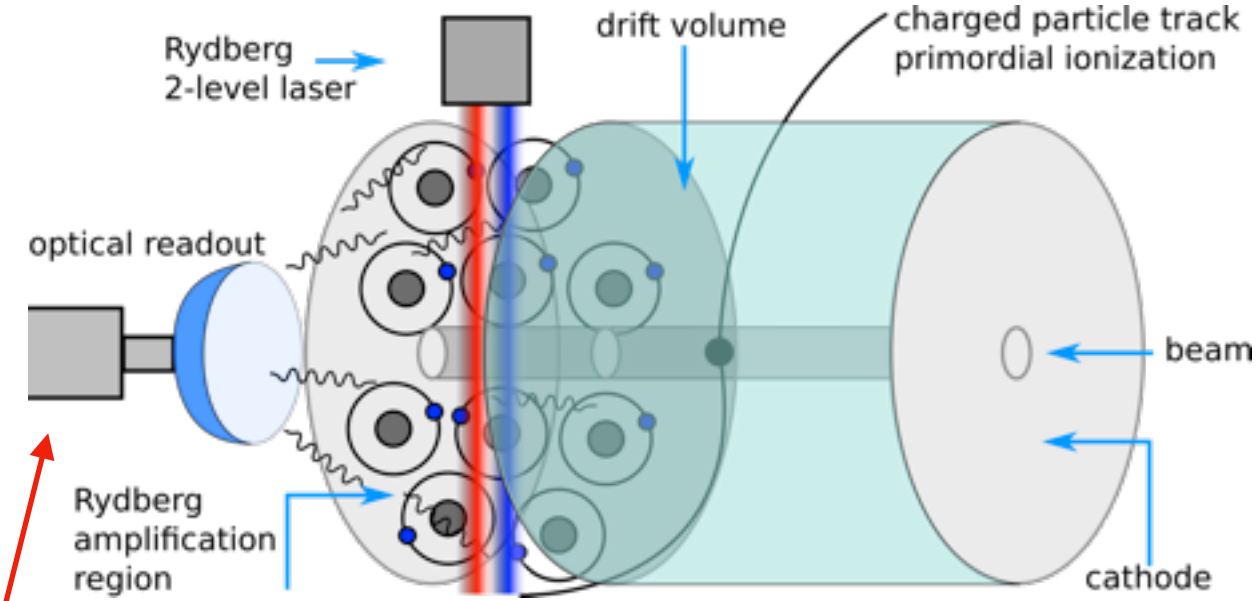
Superconducting sensors

3 Rydberg atom TPC's

Georgy Kornakov / WUT

Act on the amplification region





enhanced electron signal through "priming" of gas in amplification region: → effective reduction of ionization threshold of gas in amplification region → higher electron yield

Rydberg atoms can serve to up-convert THz / GHz radiation into the optical regime → optical R/O of avalanche intensities

Metamaterials, 0 / 1 / 2-dimensional materials (quantum dots, nanolayers)

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- chromatic calorimetry (QDs)
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Atoms, molecules, ions

- Rydberg TPC's

Spin-based sensors

- helicity detectors

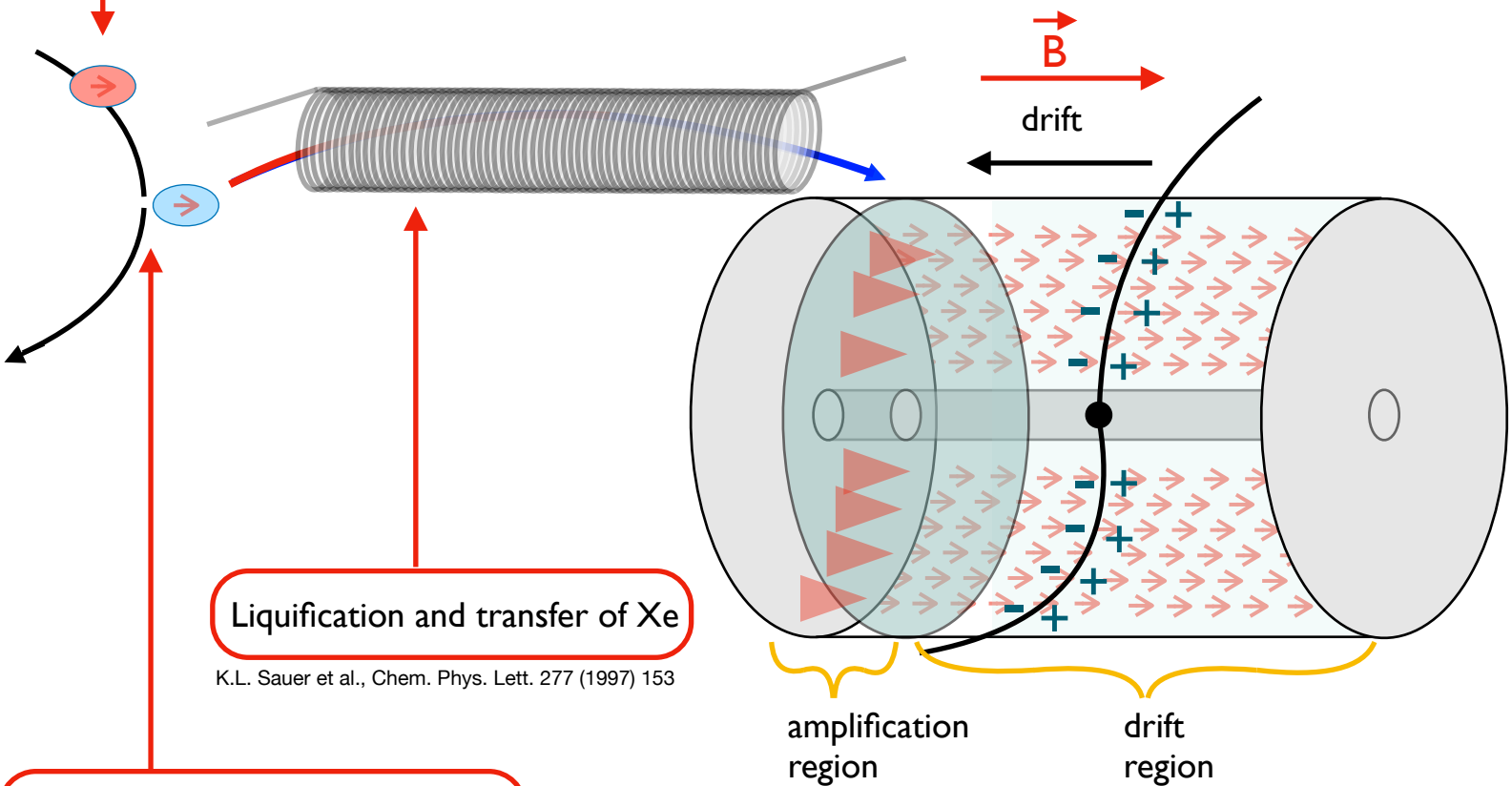
Superconducting sensors

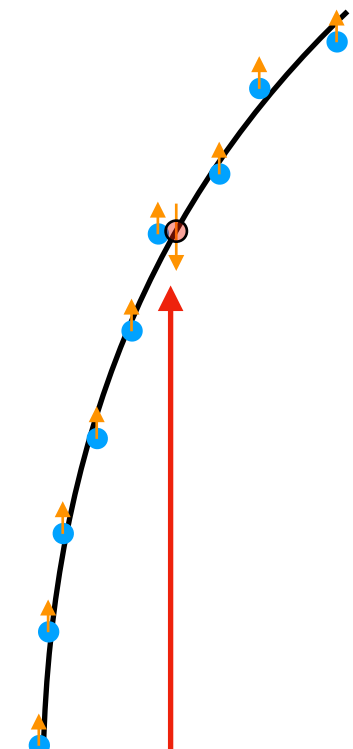
3 Polarized TPC's

Xe (Kr, Ar) can be sympathetically polarized by interaction with optically polarized Rb

Spin Hyperpolarization in Modern Magnetic Resonance, J. Eills et al., Chem. Rev. 123 (2023), https://doi.org/10.1021/acs.chemrev.2c00534

Laser polarization of Rb





Liquification and transfer of Xe

K.L. Sauer et al., Chem. Phys. Lett. 277 (1997) 153

Transfer of Rb polarization to Xe

Spin exchange optical pumping hyperpolarization

G. Norquay et al., Phys. Rev. Lett. 121, 153201

Spin-spin scattering of helicity +1/-1 particle on polarized "target" ⟶ helicity determination

N. Lockyer et al., Phys. Rev. D 30 (1984) 860;
C.X. Lin et al., arXiv:2512.02804v1 (2025);
Y.T. Liang et al., Phys. Rev. D 112 (2025) L031502

Metamaterials, 0 / 1 / 2-dimensional materials (quantum dots, nanolayers)

- ultra-fast scintillators based on perovskytes
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Atoms, molecules, ions

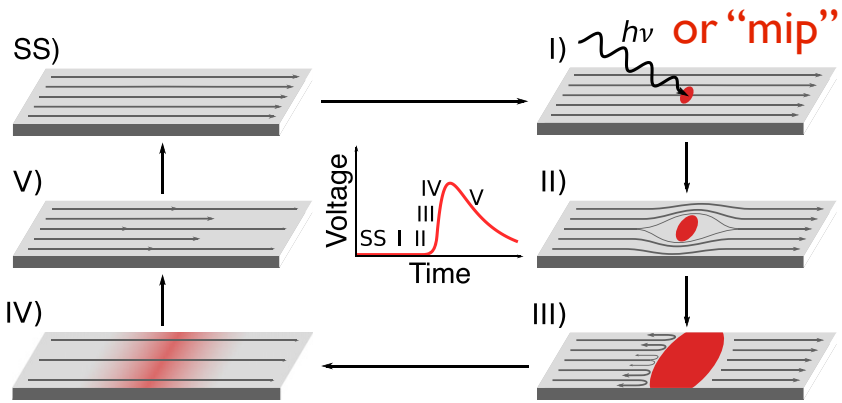
- Rydberg TPC's

Spin-based sensors

- helicity detectors

Superconducting sensors

3 Extremely low energy threshold detectors: SNSPD



SNSPD's Near term future

Parameter	SOA 2020	(;
Efficiency	98% @ 1550nm	>80 % @10μm
Energy Threshold	0.125 eV (10 μm)	12.5 meV (100 μm)
Timing Jitter	2.7 ps	< 1ps
Active Area	1 mm^2	100 cm^2
Max Count Rate	1.2 Gcps	100 Gcps
Pixel Count	1 kilopixel	16 megapixel
Operating Temperature	4.3K	25 K

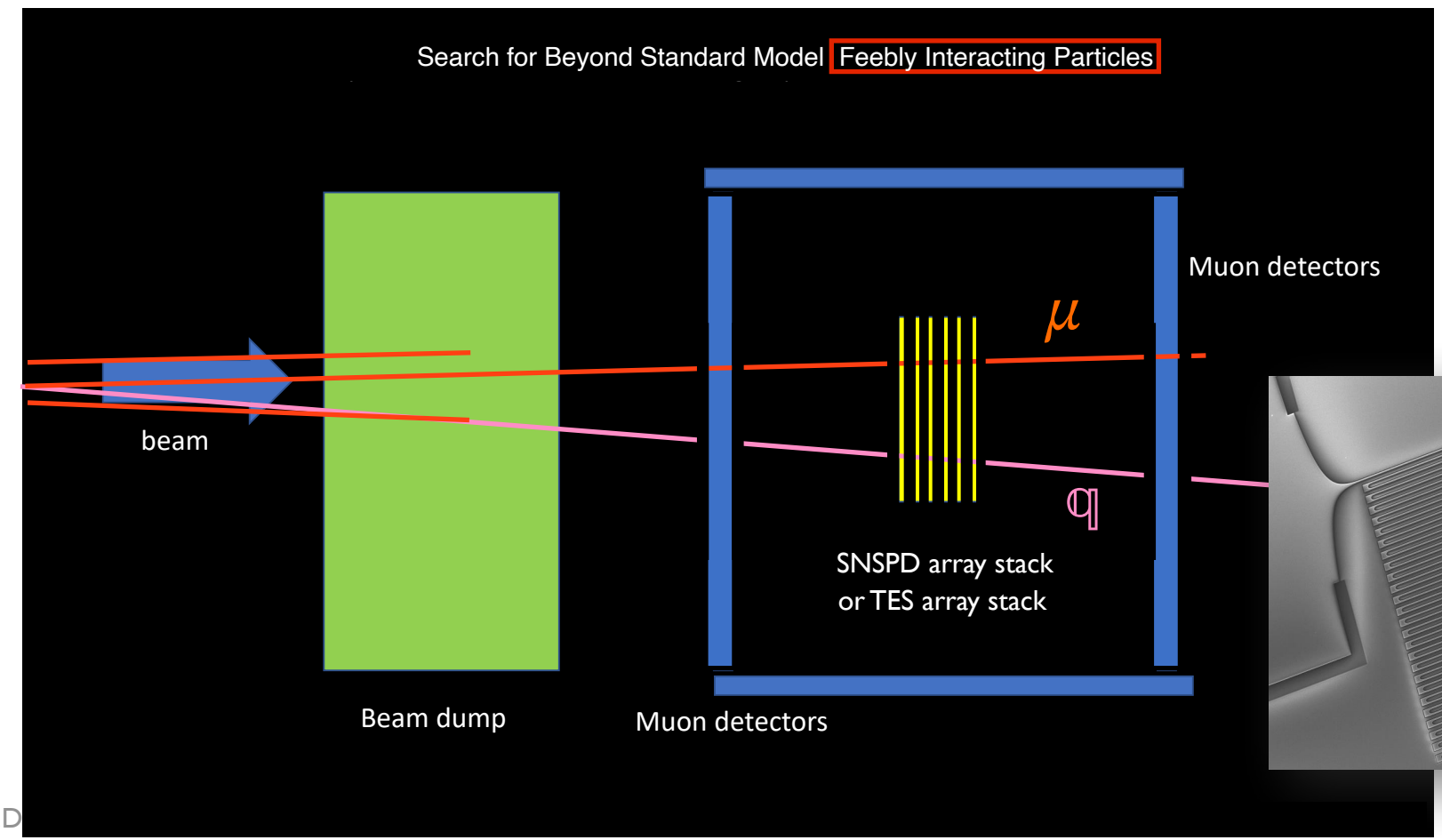
Snowmass2021 - Letter of Interest

Superconducting Nanowire Single-Photon Detectors

Moving to SC strips conventional lithography → scale up
Development towards SC SSPM

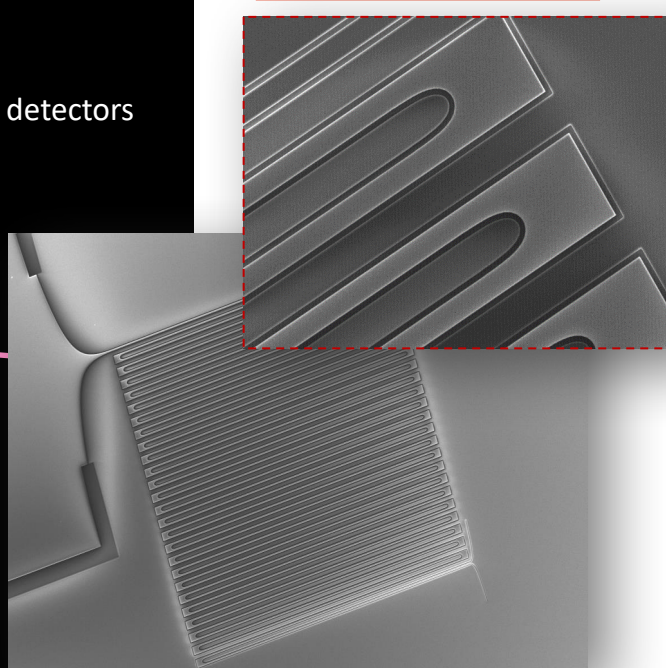
QT4HEP22-- I. Shipsey

Contact Information:
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Matt Shaw, mattshaw@jpl.nasa.gov



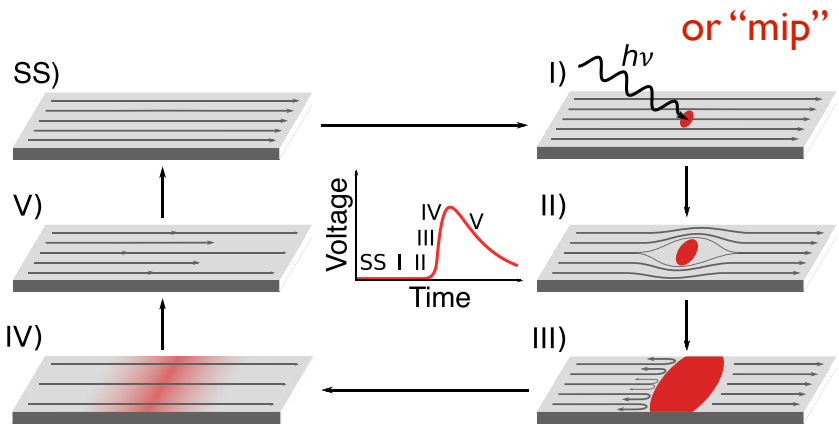
mip: ~20 keV/100 μm

x 10^6 sensitivity



3 Extremely fast detectors: SNSPD

SNSPD's Near term future



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Efficiency	98% @ 1550nm	>80 % @10μm
Energy Threshold	0.125 eV (10 μm)	12.5 meV (100 μm)
Timing Jitter	2.7 ps	< 1ps
Active Area	1 mm^2	100 cm^2
Max Count Rate	1.2 Gcps	100 Gcps
Pixel Count	1 kilopixel	16 megapixel
Operating Temperature	4.3K	25 K

Snowmass2021 - Letter of Interest

Superconducting Nanowire Single-Photon Detectors

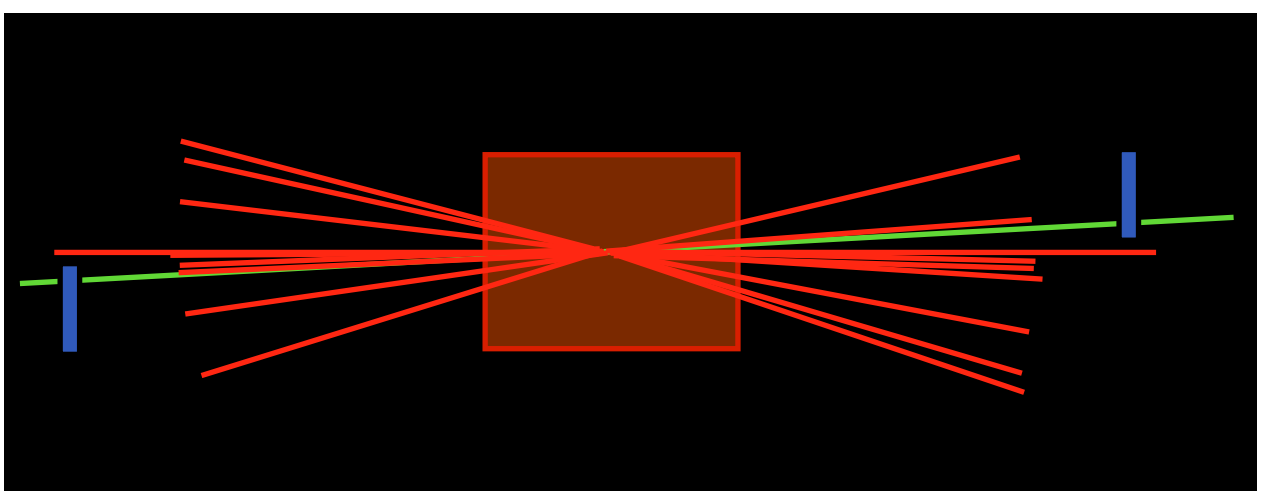
Contact Information:
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Valentine Novosad, novosad@anl.gov
Boris Korzh, bkorzh@jpl.nasa.gov
Matt Shaw, mattshaw@jpl.nasa.gov

Moving to SC strips conventional lithography → scale up
Development towards SC SSPM

QT4HEP22-- I. Shipsey

1

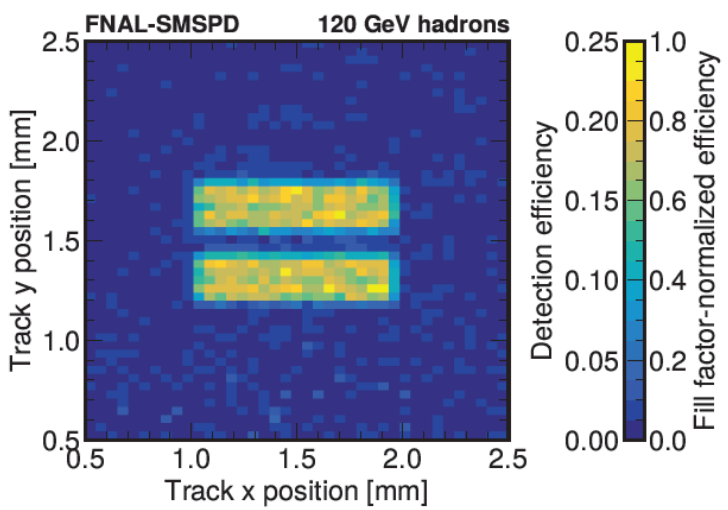
diffractive scattering via ps-resolution tracking in Roman pots



low energy particle physics: dark count rate is critical !
high energy particle physics: dark count rate is not a problem: high Tc is imaginable

Beam test results with SMSPD's @ SPS

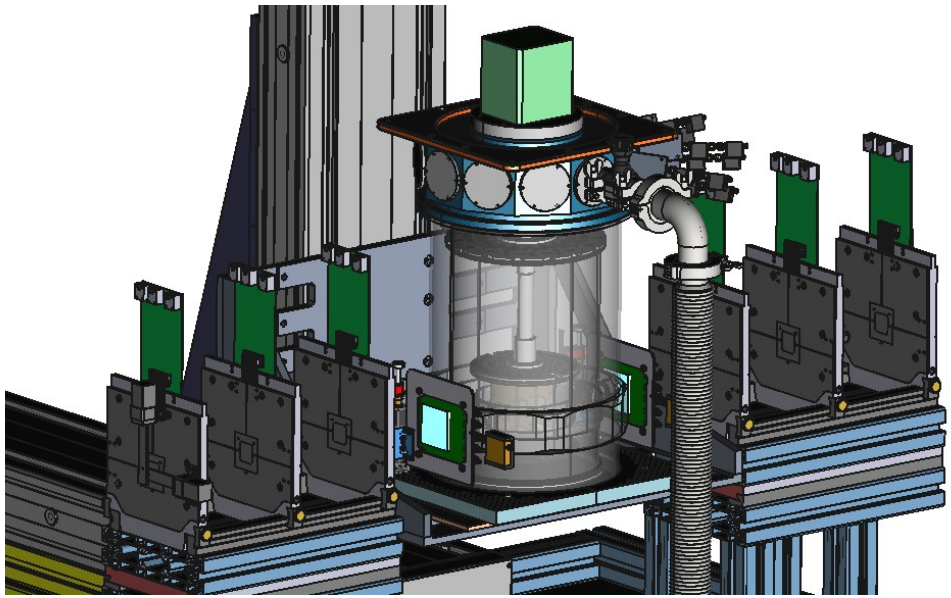
Adi Bornheim / FNAL



Beam test results with SNSPD's @ SPS

- particle detection with NbTiN and MbB_2 films
- 100 psec timing

3 Cryogenic test beam set-up at CERN for SNSPD's, TES's, QD's, NV…



V. Gkougkousis Uni Zürich (vagelis.gkougkousis@cern.ch)

Second prototype (K2): B. Korzh Uni Geneva (boris.korzh@cern.ch)

- All components purchased and received by UNIGE in 2026
- Modifications requested by DRD5 community beyond K1:
  - Increase pre-cooler cooling power: 0.9 W
  - Increase width of lowest stage: 40 cm
- Accessible stages for sample mounting in front of beam path:
  - 300 mK
  - 800 mK
  - 3 K - with heaters such that it can be warmed up to 20 K and stabilized

CERN prototype (C1): CERN Quantum Technology Initiative - II

- Clone of K2
  - With minor improvements/fixes following prototyping
- Commissioning by mid-2028 ready for test beams
- Procurements will start as soon as DRD5 approves

Future CERN prototype (C2):

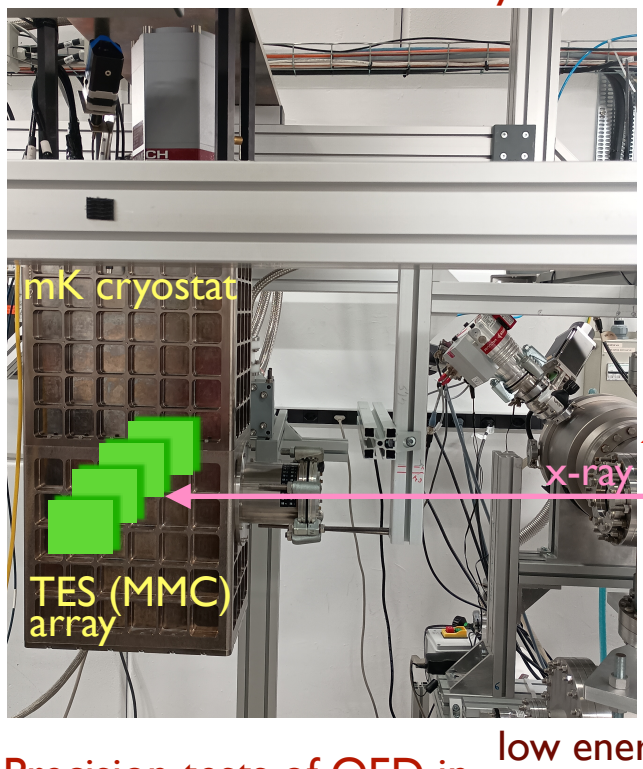
- If community maintains interest
- Accessible stages for sample bracket mounting in front of beam path:
  - 60-100 mK
  - 3 K - with heaters such that it can be warmed up to 20 K and stabilized
- Form factor: same as K2 / C1
- Potential timeline: 2029/2030

Beam telescopes, controls systems, DAQ G. Kornakov (georgy.Kornakov@cern.ch)

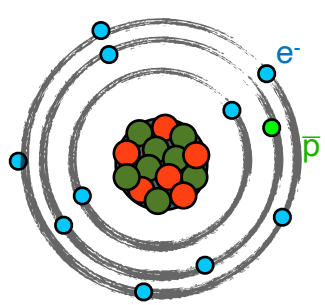
but also TELMAX $\bar{p}$ test beam line

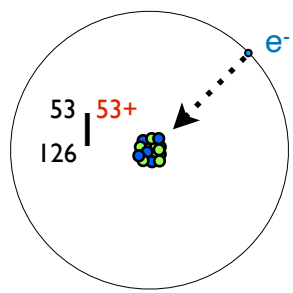
$\bar{p}$A x-ray spectroscopy (PAX)

Nancy Paul / LKB



Precision tests of QED in strong field ($\Delta E/E \sim 1eV$ @ 10 keV)





AION: atom interferometer (start small, ultimately → space)

L. Badurina et al., AION: An Atom Interferometer Observatory and Network, JCAP 05 (2020) 011, [arXiv:1911.11755].
arXiv:2201.07789v1 [astro-ph.IM] 19 Jan 2022

Topological Dark Matter (TDM)

~ scalar field that couples to fundamental constants, thus producing variations in the transition frequencies of atomic clocks at its passage

Ultralight Dark Matter

spatial variation of the fundamental constants associated with a change in the gravitational potential

Local Lorentz Invariance (LLI)

independence of any local test experiment from the velocity of the freely-falling apparatus: search for daily variations of the relative frequency difference between 2 clocks with different spatial orientation

Local Position Invariance (LPI)

independence of any local test experiment from when and where it is performed in the Universe; here,compare atomic clocks based on different transitions to constrain the time variation of fundamental constants and their couplings

Gravitational wave detector

clocks act as narrowband detectors of the Doppler shift on the laser frequency due to the relative velocity between the satellites induced by the incoming gravitational wave

R & D needed:

Optical lattice clocks at up to 1×10^{-18} relative accuracy

& expanded optical fibre network (operated between a number of European metrology institutes)

& develop cold atom technology for robust, long-term operation

Where does this fit in? Go after 10^{-20} eV < m_a < 10^{-12} eV

1 atom interferometry at macroscopic scales:

arXiv:2201.07789v1 [astro-ph.IM] 19 Jan 2022

AION[UK] MIGA[France] MAGIS[Fermilab] ZAIGA[China]

CERN? AICE

shafts (100~500 m ideal testing ground),
cryogenics, vacuum, complexity…

M. Abe, P. Adamson, M. Borcean, D. Bortoletto, K. Bridges, S. P. Carman et al., Matter-wave Atomic Gradiometer Interferometric Sensor (MAGIS-100), arXiv:2104.02835v1.

MAGIS collaboration, Graham PW, Hogan JM, Kasevich MA, Rajendran S, Romani RW. Mid-band gravitational wave detection with precision atomic sensors. arXiv:1711.02225

2 satellite missions:

ACES (Atomic Clock Ensemble in Space)

ESA mission for ISS 2025-2028

On 28 April 2025, ACES was successfully switched on the ISS for the first time

pathfinder / technology dev. missions ~ 2030

I-SOC: key optical clock technology (laser cooling, trapping, optical resonators) for space; Sr optical lattice clock / Sr ion clock; microwave and optical link technology;

FOCOS (Fundamental physics with an Optical Clock Orbiting in Space): Yb optical lattice clock with 1×10^{-18} stability

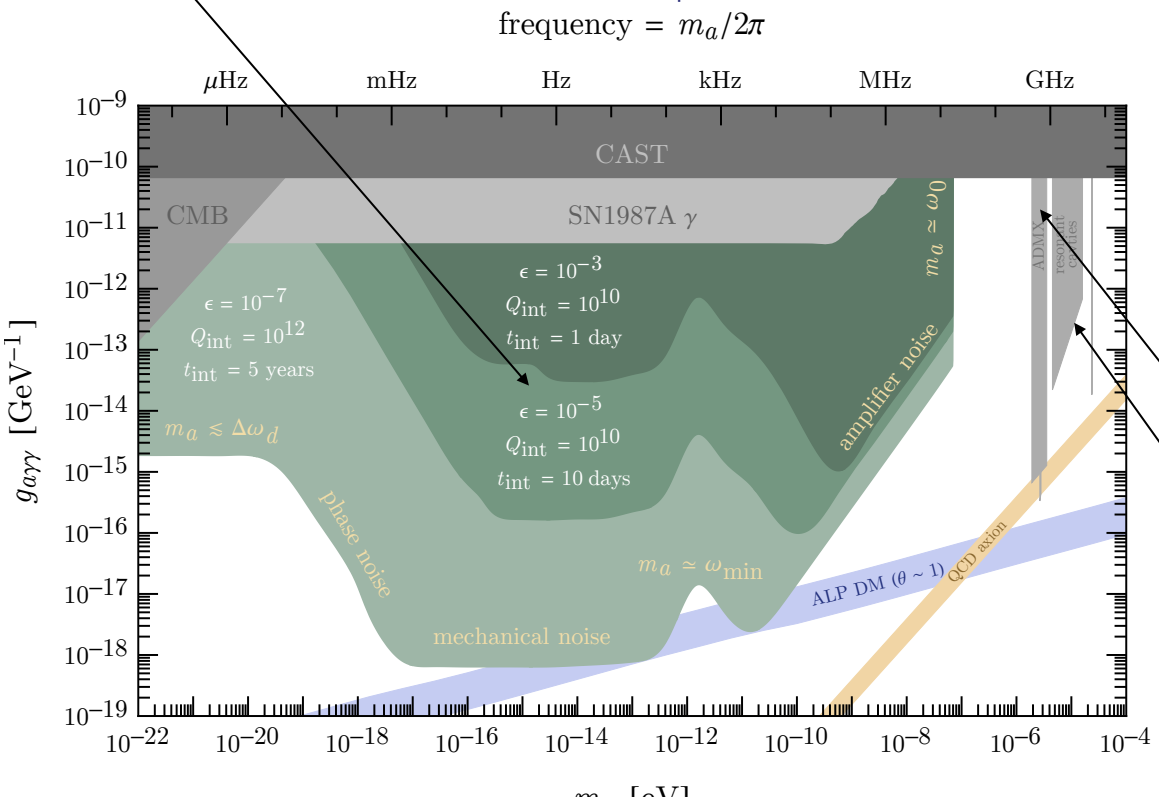
AEDGE: ~2045

El-Neaj, Y.A., Alpigiani, C., Amairi-Pyka, S. *et al*. AEDGE: Atomic Experiment for Dark Matter and Gravity Exploration in Space. *EPJ Quantum Technol*. **7,** 6 (2020). https://doi.org/10.1140/epjqt/s40507-020-0080-0

Axion heterodyne detection

$Q_{int} \gtrsim 10^{10}$ achieved by DarkSRF collaboration
(sub-nm cavity wall displacements)

A. Grassellino, "SRF-based dark matter search: Experiment," 2019. https://indico.fnal.gov/event/19433/session/2/ contribution/2/material/slides/0.pdf



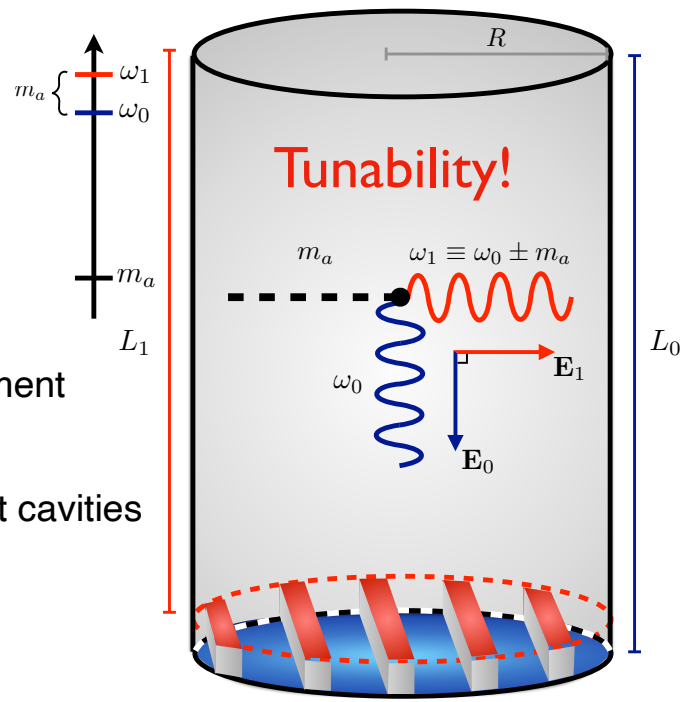
ADMX experiment

resonant cavities

problem: cavity resonance generally fixed

Resonant cavities possible down to μeV; below that, need huge volume

driving "pump mode" at $\omega_0 \sim$ GHz allows axion to resonantly drive power into "signal mode" at $\omega_1 \sim \omega_0 \pm m_a$



(a) Cartoon of cavity setup.

Conceptual Theory Level Proposal:

A. Berlin, Raffaele Tito D'Agnolo, S. Ellis, C. Nantista, J. Nielson, P. Schuster, S. Tantawi, N. Toro, K. Zhou, *JHEP* 07 (2020) 07, 088

Asher Berlin, Raffaele Tito D'Agnolo, Sebastian A. R. Ellis, Christopher Nantista, Jeffrey Neilson, Philip Schuster, Sami Tantawi, Natalia Toro, Kevin Zhou, https://arxiv.org/abs/1912.11048

"The cavity is designed to have two nearly degenerate resonant modes at ω_0 and $\omega_1 = \omega_0 + m_a$. One possibility is to split the frequencies of the two polarizations of a hybrid HE_{11p} mode in a corrugated cylindrical cavity. These two polarizations effectively see distinct cavity lengths, L_0 and L_1, allowing ω_0 and ω_1 to be tuned independently."

Needed! : major developments on integrated cryoelectronics (4K)

"Quantum" is relevant (also for HEP) → DRD5

DRD5 WP \ HEP function	Tracking	Calorimetry	Timing	PID	Helicity
WP 1 (Quantum systems in traps and beam)	Rydberg TPC	BEC WIMP scattering (recoil)	O(fs) reference clock for time-sensitive synchronization (photon TOF)	Rydberg dE/dx amplifiers	Helicity detector via transfer of atomic polarization to bulk
WP2 (Quantum materials: 0-, 1- and 2-D)	"DotPix"; improved GEM's; chromatic tracking (sub-pixel); active scintillators	Chromatic calorimetry	Suspended / embedded quantum dot scintillators O(<ps) optical charged particle detection	Photonic dE/dx through suspended quantum dots in TPC	
WP 3 (Superconducting quantum devices)	O(ps) SNSPD trackers for diffractive scattering (Roman pot)	FIR, UV & x-ray calorimetry	O(ps) high Tc SNSPD	Milli- & microcharged particle trackers in beam dumps	
WP 4 (scaled-up bulk systems for mip's)	Multi-mode trackers (electrons, photons)	Multi-mode calorimeters (electrons, photons, phonons)	Wavefront detection (e.g. O(ps) embedded devices)		Helicity detector via ultra-thin NV optically polarized scattering / tracking stack
WP 5 (Quantum techniques)				Many-to-one entanglement detection of interaction	
WP 6 (capacity building)	Technical expertise of future workforce (detector construction); broadened career prospects and thus enhanced attractiveness; cross-departmental networking and collaboration; broadened user base for infrastructure (beam tests, dilution refrigerators, processing technologies)				

(under way; in preparation; under discussion or imaginable applications; long-range potential)

Infrastructure @ CERN — CERN QTI

DRD5: WP's (particle physics > HEP)

WP1 Exotic systems in traps & beams (HCI's, molecules, Rydberg systems, clocks, interferometery, …)

WP2 Quantum materials (0-, 1-, 2-D) (Engineering at the atomic scale)

WP3 Quantum superconducting systems (4K electronics; MMC's, TES, SNSPD, KID's/…; integration challenges)

WP4 Scaling up to macroscopic ensembles (spins; nano-structured materials; hybrid devices, opto-mechanical sensors,…)

WP5 Quantum techniques for sensing (back action evasion, squeezing, entanglement, Heisenberg limit)

WP6 Capability expansion (cross-disciplinary exchanges; infrastructures; education)

4

DRD5: 120 involved groups

Detector R&D: quantum sensors for particle physics

UK: Oxford University, Univ. of Warwick, Univ. of Birmingham, NPL, Imperial College, Univ. of Southhampton, Univ. of Sussex, Univ. of Liverpool, Univ. of Manchester

Ireland: University College of Cork

France: CNRS - U. Sorbonne Paris Nord, LKB, ILM - University Lyon 1, IRFU / CEA Saclay

Canada: McGill Univ., TRIUMF

USA: ORNL, Northwestern Univ., Caltech, MIT, Arizona State Univ., Univ. of Arizona, NIST, LBNL, Univ. of Delaware, FNAL, SLAC

Mexico: U. de Aguascalientes

Spain: Univ. de Santiago de Compostela, U. de Cartagena, U. de Valencia, U. de Lleida, IEM, CSIC, Inst. Microelectronics Barcelona, Inst. Fisica de Cantabria, Univ. de Zaragoza, Inst. Tech. de Aragón

Switzerland: U. of Geneva, U. of Zürich, CERN, ETHZ, Univ. Bern

Austria: IQOQI Vienna, TU Wien

Croatia: Inst. of Physics, Zagreb, Univ. of Rijeka

Israel: Technion, Haifa

South Africa: U. of Cape Town

India: IITT, Tirupati, IEM, Kolkata, TIFR, Mumbai, LPU, Punjab, University SOA Bhuvaneswar

Iran: Isfahan U. of Tech.

Macau: IAP, University of Macau

China: IHEP, USTC (Hefei)

Australia: University of Western Australia, Swinburne University of Technology, University of Sydney

Taiwan: Academia Sinica & NTU

Japan: QUP / KEK, Kyoto University, Tokyo University / ICEPP, University of Shizuoka

Czech Republic: Charles Univ., Prague, Czech Tech. University, University West Bohemia

Poland: Warsaw TU, Nat. Centre Nucl. Research / Warsaw, Nicolaus Copernicus University / Torun

Finland: Helsinki Inst. of Physics, VTT

Italy: U. of Pisa & INFN, U. of Pavia, U. of Firenze, U. of Milano-Bicocca, Fondazione Bruno Kessler, Trento, IOM CNR & Elettra Sincrotrone, Trieste, Univ. of Bari / INFN, INFN Padova, Univ. Roma 1 & 3, Univ. Napoli, INFN Roma Tor Vergata, INFN LNF, INFN Trento (TIFPA), INFN Torino, INFN LNL, INFN Lecce, INFN Roma 1, U. of Camerino

Germany: GSI, DLR (Deutsch. Zentr. Luft- u. Raumfahrt), PTB, Univ. Ulm, Leibnitz Univ. Hannover, KIT, Karlsruhe, TU München, DESY, MPP Garching, HU Berlin, FBH Berlin, Univ. Heidelberg, Univ. Tübingen, Univ. Düsseldorf, Univ. Mainz, Semiconductor Lab HLL / MPG, TU Darmstadt

Türkiye: Sabanci University, Istanbul; Düzce University; Ankara University, Ankara; Izmir University; Istinye University, Istanbul

Hungary: Wigner Institute

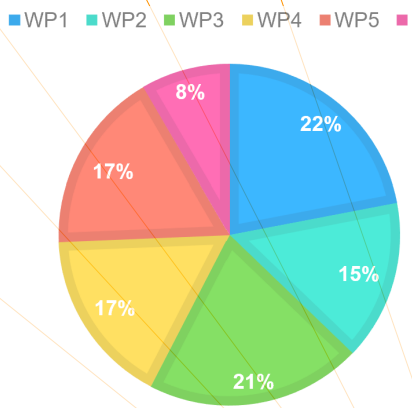
Lithuania: University of Vilnius

Denmark: Aarhus University

Sweden: Stockholm University

Norway: Oslo University

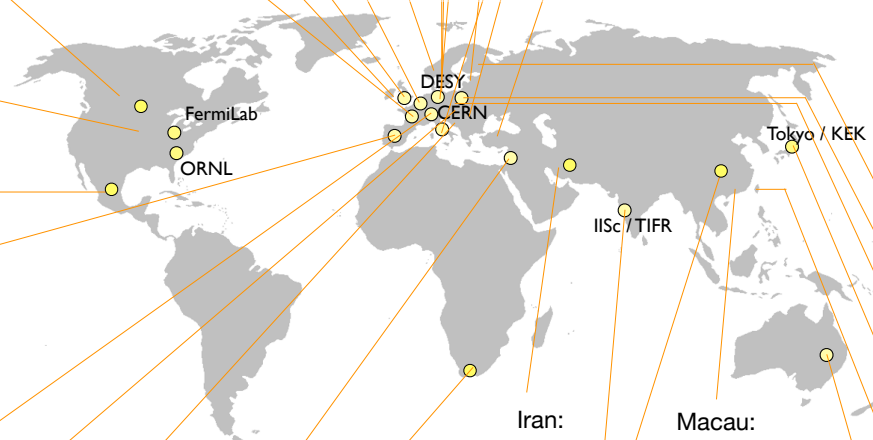
Netherlands: U. of Groningen



Applied (detectors)

Fundamental physics

Improved quantum measurements



4

DRD5: 120 involved groups

Detector R&D: quantum sensors for particle physics

UK: Oxford University, Univ. of Warwick, Univ. of Birmingham, NPL, Imperial College, Univ. of Southhampton, Univ. of Sussex, Univ. of Liverpool, Univ. of Manchester

Ireland: University College of Cork

France: CNRS - U. Sorbonne Paris Nord, LKB, ILM - University Lyon 1, IRFU / CEA Saclay

Canada: McGill Univ., TRIUMF

USA: ORNL, Northwestern Univ., Caltech, MIT, Arizona State Univ., Univ. of Arizona, NIST, LBNL, Univ. of Delaware, FNAL, SLAC

Mexico: U. de Aguascalientes

Spain: Univ. de Santiago de Compostela, U. de Cartagena, U. de Valencia, U. de Lleida, IEM, CSIC, Inst. Microelectronics Barcelona, Inst. Fisica de Cantabria, Univ. de Zaragoza, Inst. Tech. de Aragón

Switzerland: U. of Geneva, U. of Zürich, CERN, ETHZ, Univ. Bern

Netherlands: U. of Groningen

Norway: Oslo University

Sweden: Stockholm University

Denmark: Aarhus University

Lithuania: University of Vilnius

Hungary: Wigner Institute

Türkiye: Sabanci University, Istanbul; Düzce University; Ankara University, Ankara; Izmir University; Istinye University, Istanbul

Germany: GSI, DLR (Deutsch. Zentr. Luft- u. Raumfahrt), PTB, Univ. Ulm, Leibnitz Univ. Hannover, KIT, Karlsruhe, TU München, DESY, MPP Garching, HU Berlin, FBH Berlin, Univ. Heidelberg, Univ. Tübingen, Univ. Düsseldorf, Univ. Mainz, Semiconductor Lab HLL / MPG, TU Darmstadt

Italy: U. of Pisa & INFN, U. of Pavia, U. of Firenze, U. of Milano-Bicocca, Fondazione Bruno Kessler, Trento, IOM CNR & Elettra Sincrotrone, Trieste, Univ. of Bari / INFN, INFN Padova, Univ. Roma 1 & 3, Univ. Napoli, INFN Roma Tor Vergata, INFN LNF, INFN Trento (TIFPA), INFN Torino, INFN LNL, INFN Lecce, INFN Roma 1, U. of Camerino

Finland: Helsinki Inst. of Physics, VTT

Poland: Warsaw TU, Nat. Centre Nucl. Research / Warsaw, Nicolaus Copernicus University / Torun

Czech Republic: Charles Univ., Prague, Czech Tech. University, University West Bohemia

Japan: QUP / KEK, Kyoto University, Tokyo University / ICEPP, University of Shizuoka

Taiwan: Academia Sinica & NTU

Australia: University of Western Australia, Swinburne University of Technology, University of Sydney

India: IITT, Tirupati, IEM, Kolkata, TIFR, Mumbai, LPU, Punjab, University SOA Bhuvaneswar

Israel: Technion, Haifa

South Africa: U. of Cape Town

Croatia: Inst. of Physics, Zagreb, Univ. of Rijeka

Austria: IQOQI Vienna, TU Wien

Iran: Isfahan U. of Tech.

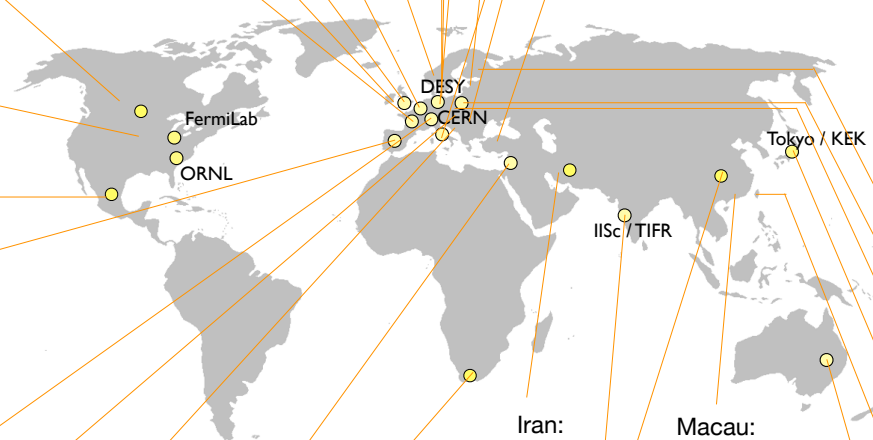
Macau: IAP, University of Macau

China: IHEP, USTC (Hefei)

Collaboration ramping up, combines diverse communities, including HEP.

Many novel developments that benefit both quantum technologies and particle physics.

Open to all interested parties (and it's free to join!)



thank you!

4

What is DRD5 built to do?

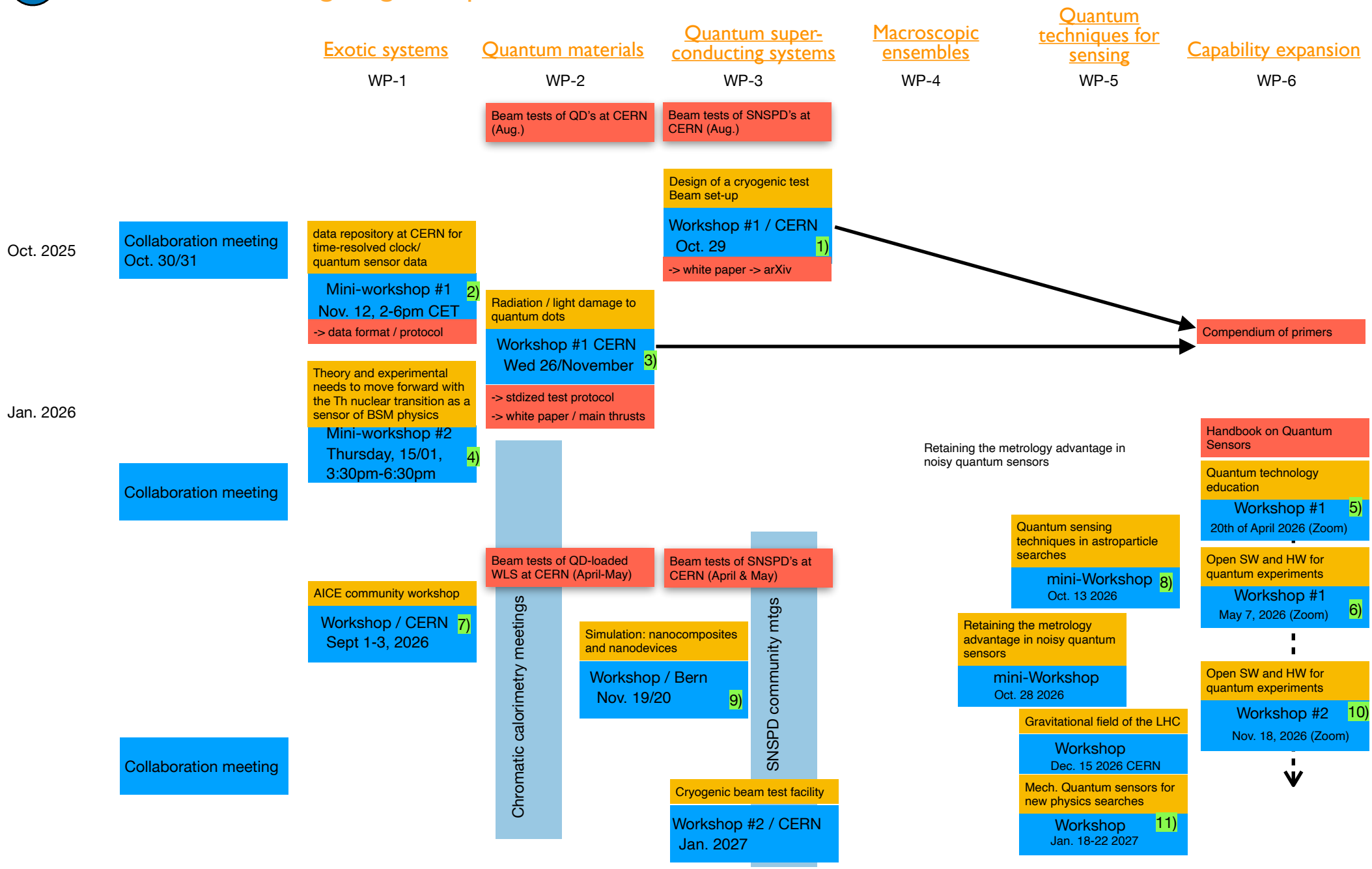
- focus on addressing topics that go *beyond what individual institutes* can do
- pool expertise, resources, create exchanges, educate
- create a global multi quantum-technology community focusing on quantum systems based detector R&D under the umbrella of DRD5

What has happened since the DRD5 was formed and approved in mid-2024?

- concrete proposals for *HEP-relevant* uses of quantum sensors are appearing
- first beam tests with quantum dots and nano/microwires
- formation of a global multi quantum-technology community focusing on detector R&D under the umbrella of DRD5
- infrastructure needs have been identified and are starting to be addressed (cryogenic beam test facilities, quantum dot characterization infrastructure, …)

https://drd5.web.cern.ch

DRD5 : ongoing and planned activities



1) https://indico.cern.ch/event/1580512/ 2) https://indico.cern.ch/event/1598214 3) https://indico.cern.ch/event/1598214 4) https://indico.cern.ch/event/1624634 5) https://indico.cern.ch/event/1659242
6) https://indico.cern.ch/event/1674780/ 7) https://indico.cern.ch/event/1687915 8) https://indico.cern.ch/event/1709656/ 9) https://indico.cern.ch/event/1722003/ 10) https://indico.cern.ch/event/1727346/
11) https://indico.mitp.uni-mainz.de/event/472/

Oct. 13, 2026: WP-5: "Quantum sensing techniques in astro-particle searches" (Zoom)

Nov. 18, 2026: "Open Software and Hardware for Quantum Experiments" (Warsaw)

Nov. 19-20, 2026: "Simulation of Nanocomposites and Nanodevices" (Bern)

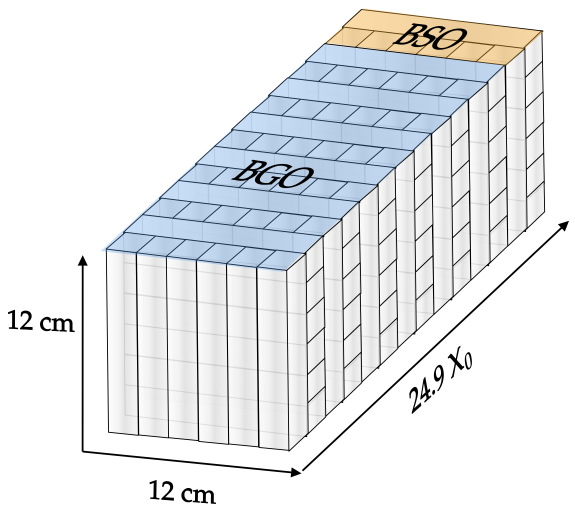
Dec. 15, 2026: "Testing gravity at the LHC" (CERN)

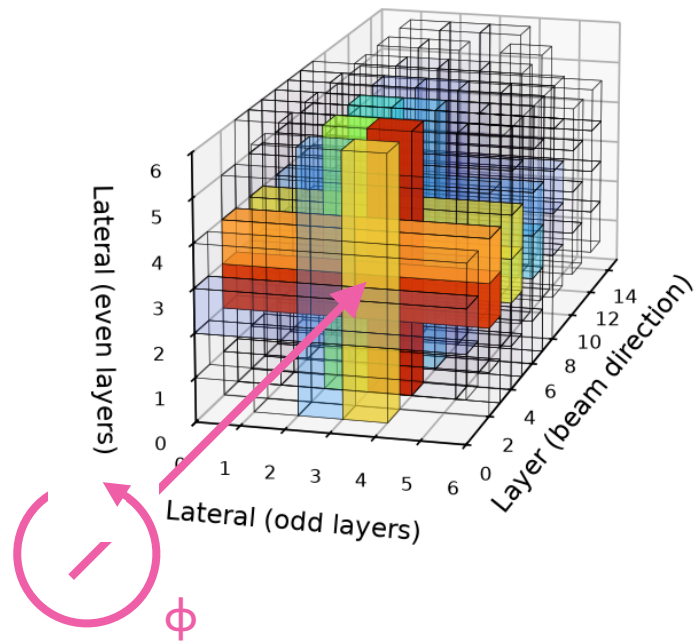
Jan. 18-22, 2027: "Mechanical Quantum Sensors for New Physics Searches" (MITP Mainz)

Jack Rolph, Yong Liu, Baohua Qi, Zhiyu Zhao
on behalf of the AGORA/CEPC Calorimetry Team

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

drdcalo





Shower shape is symmetric in ϕ

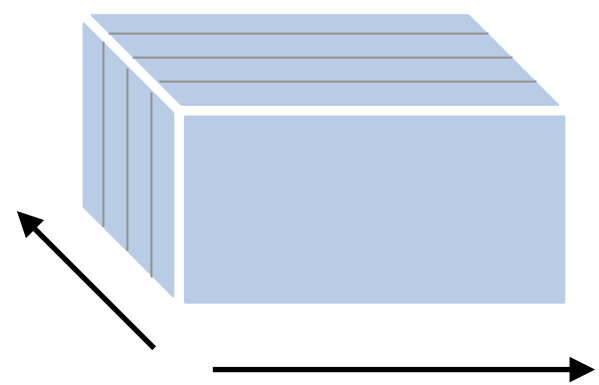
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Segmentation along one transverse axis is sufficient

↓

Axial segmentation through quantum dots

transverse segmentation:
transverse shower profile



Chromatic axis: axial shower profile