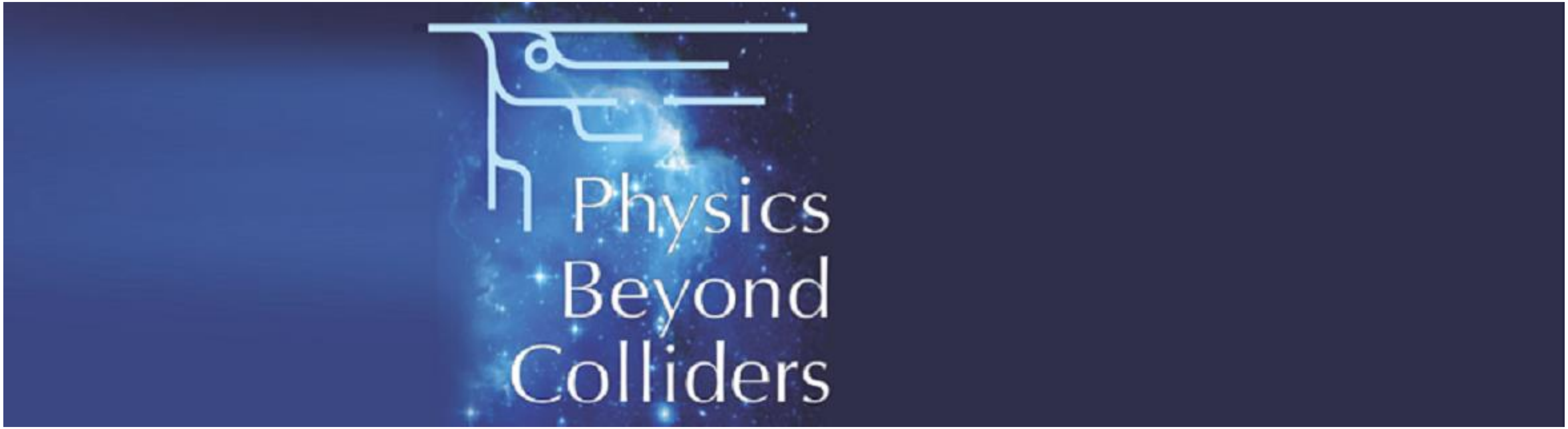

Physics
Beyond
Colliders

The Universe ☺

- Only a minor fraction of the universe, as we know it, is made of “ordinary matter”
- What are Dark Energy and Dark matter?
- Is their study part of CERN plans?
- And how?

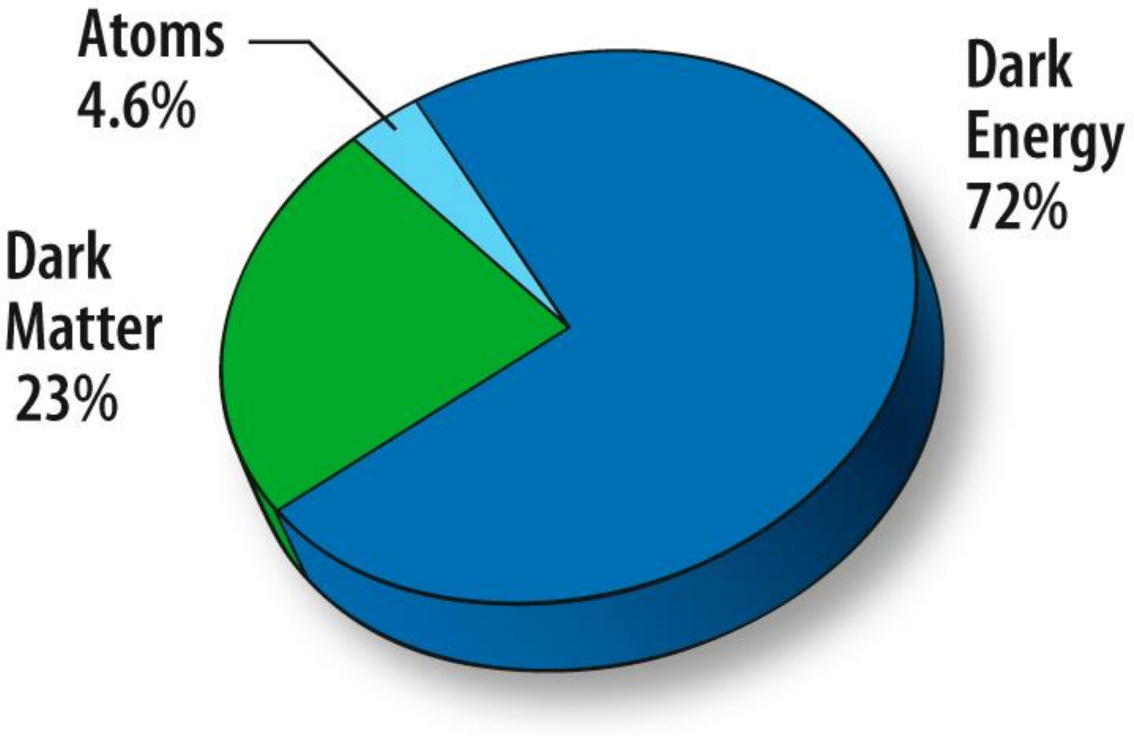
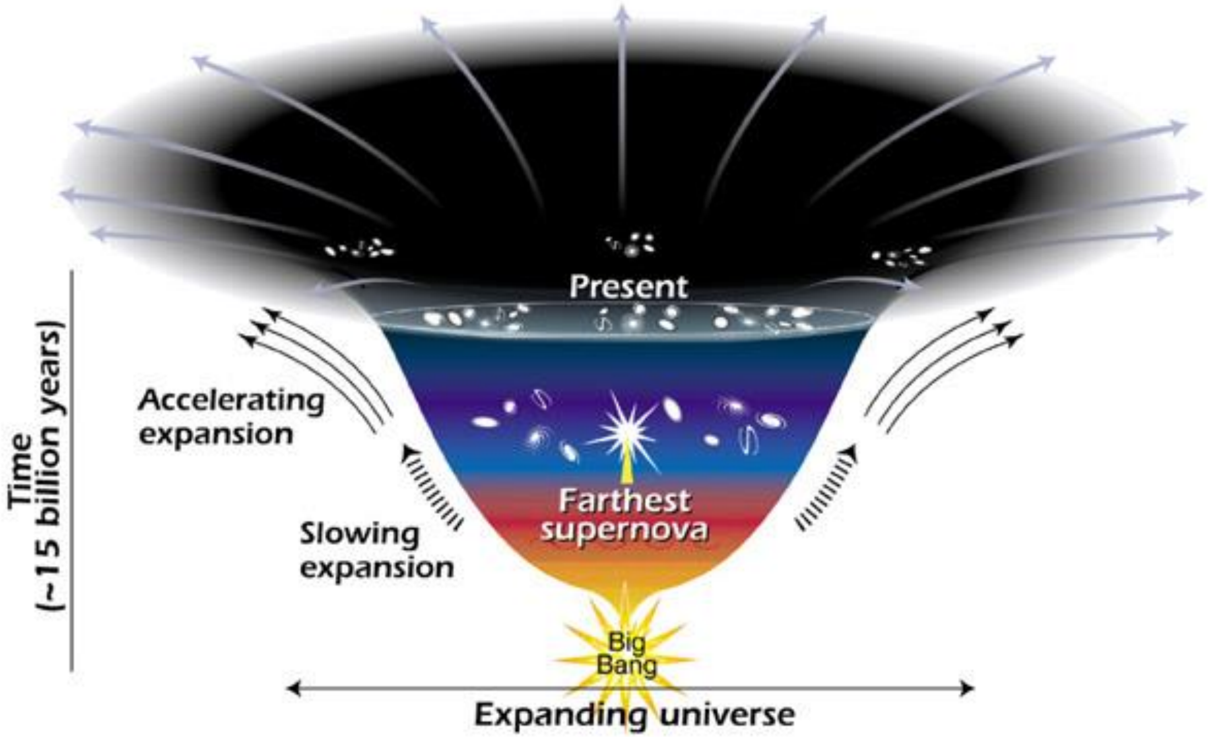


Image source: NASA / WMAP Science Team

Dark energy

- **The expansion of the universe is accelerating.**
- **This could be (main hypothesis):**
  - a property of space (Einstein general relativity);
  - or due to “quantum properties” of vacuum;
  - or to a new unknown field (“quintessence”) that fills the universe.
- **The main fact is: we do not know.**



This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the universe began flying apart at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark force that is pushing galaxies apart.

Image source: NASA/STSci/Ann Feild

Dark matter

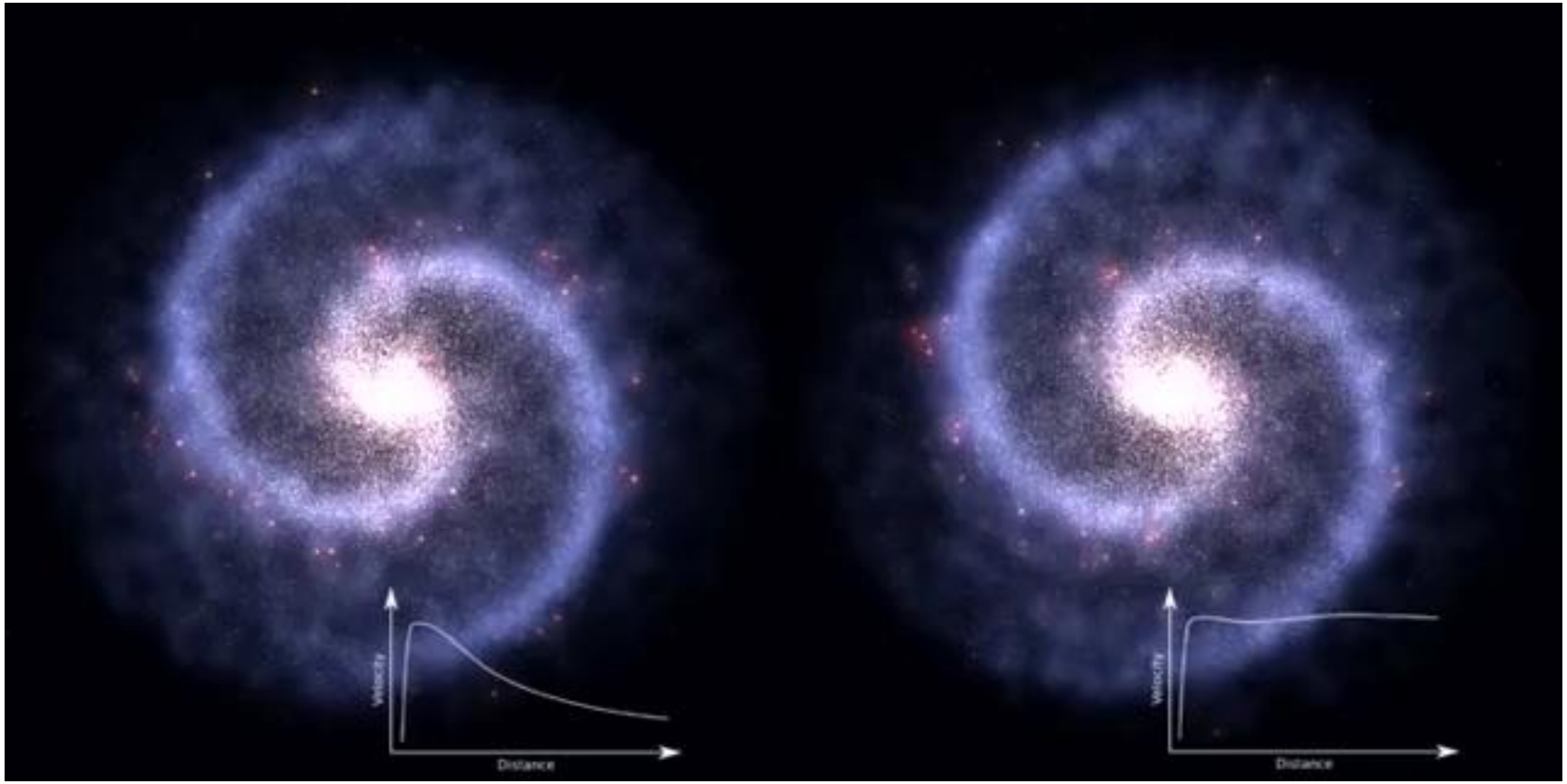
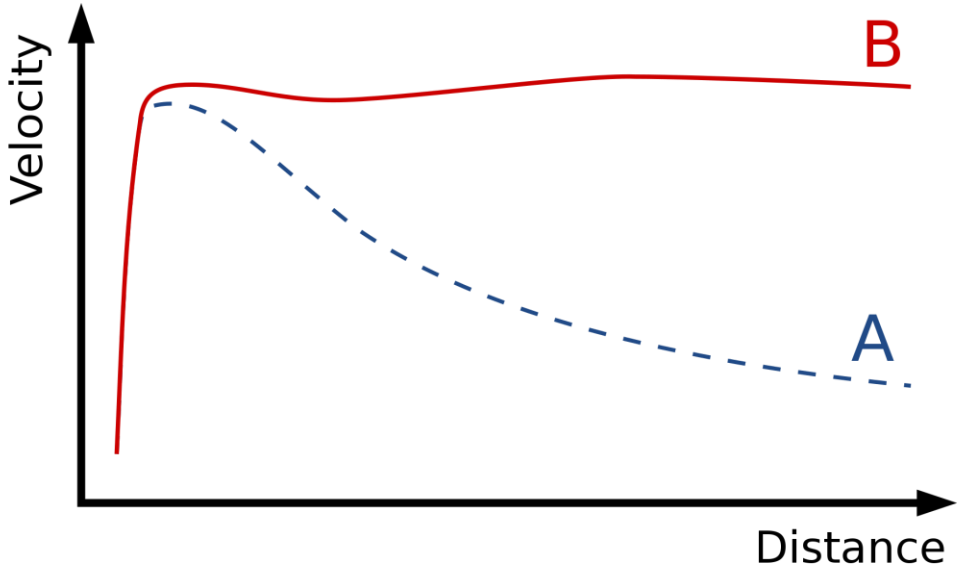


Image source: Wikipedia

Dark matter

- **Dark matter IS NOT:**
  - is not in the form of stars and planets that we see;
  - it is not in the form of dark clouds of normal matter;
  - it is not antimatter;
  - it is not large galaxy-sized black holes.
- **Dark matter MAY BE:**
  - MACHOs (MAssive Compact Halo Objects): small black holes, neutron stars, or brown dwarfs (max 20% of dark matter)
  - WIMPs (Weakly Interacting Massive Particles): subatomic particles which are not made up of ordinary matter. Axions are the best candidate

Rotation curve of a typical spiral galaxy



A predicted from the visible mass
B observed : due to dark matter?

Image source: Wikipedia

Physics Beyond Colliders

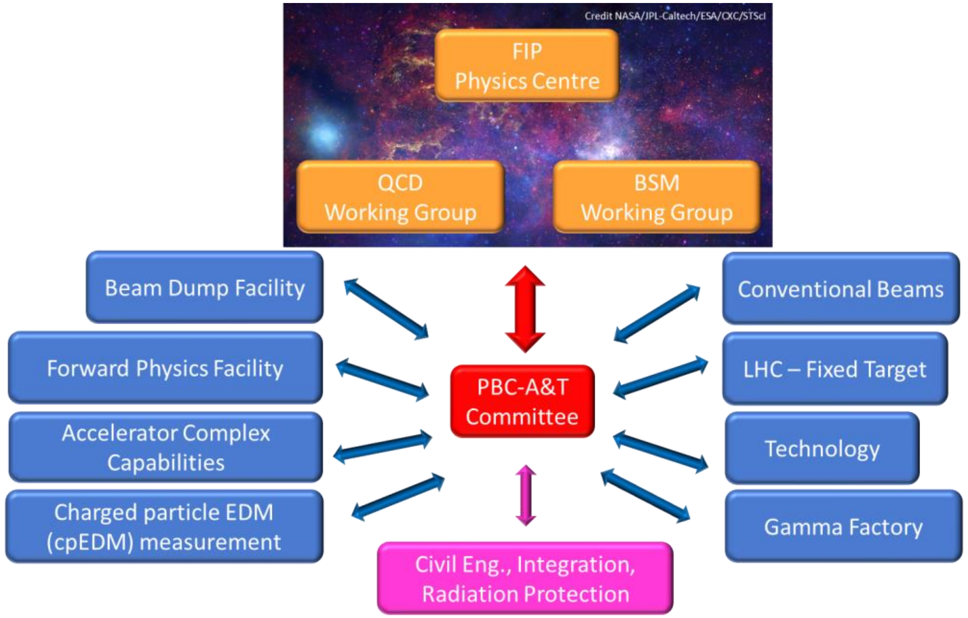
More info: Website, Workshops

From the PBC mandate

- … to address today's outstanding questions in particle physics...
- ... physics objectives include dedicated experiments for studies of rare processes and searches for feebly interacting particles...
- ... physics objectives also include projects aimed at addressing fundamental particle physics questions...
- ... PBC projects complement the goals of the main experiments of the Laboratory's collider programme (...) but require different types of beams and experiments

PBC Organization

- **Chaired by Gianluigi Arduini, Claude Vallée, Joerg Jaeckel**



- **Focus is on using CERN accelerators and technologies for innovative experiments with high physics impact**

A&T working groups

- **Accelerator Complex Capabilities**
- **Conventional Beams**

} Improvement of existing accelerators for fixed target experiments, with protons, ions etc.

- **Beam Dump Facility**

} Novel fixed target experiments at high intensity

- **Forward (and transverse) Physics Facility**
- **LHC fixed target**

} Additions to existing LHC experiments allowing higher physics potential

- **Gamma Factory**
- **Charged particle Electric Dipole Moment (cpEDM) measurement**

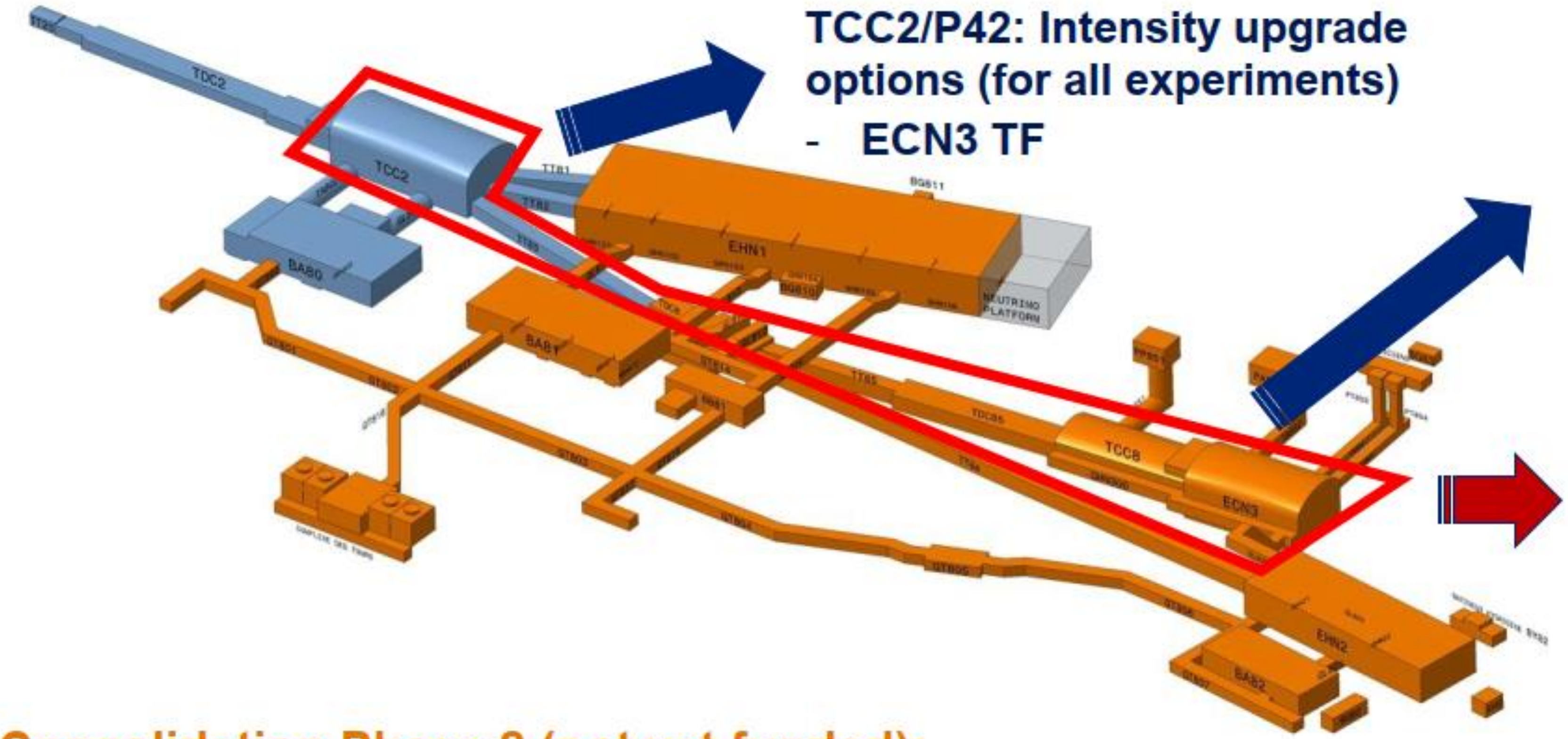
} Novel accelerator ideas

- **Technology**

} Mostly non-accelerator experiments, based on accelerator technologies

Beam dump facility and ECN3 intensity upgrade

Consolidation Phase 1 (funded):
2019 – 2028: primary areas, BA80 & beamlines towards EHN1 & TDC8



TCC2/P42: Intensity upgrade options (for all experiments)
- ECN3 TF

TCC8/ECN3: Experiment specific:
- BDF/SHiP WG
- CBWG

Beam Areas concerned with the upgrade of ECN3 to a high intensity facility

Consolidation Phase 2 (not yet funded):
2029 – 2034: BA81, BA82, EHN1, EHN2, ECN3 & associated beamlines

Image source: M. Brugger, M.A. Fraser

BDF: proposed experiments

SHiP
Search for Hidden Particles

47 Institutes – 237 Participants

HIKE
High Intensity Kaon Experiments

37 Institutes – 175 Participants

SHADOWS
Search for Hidden And Dark Objects With the SPS

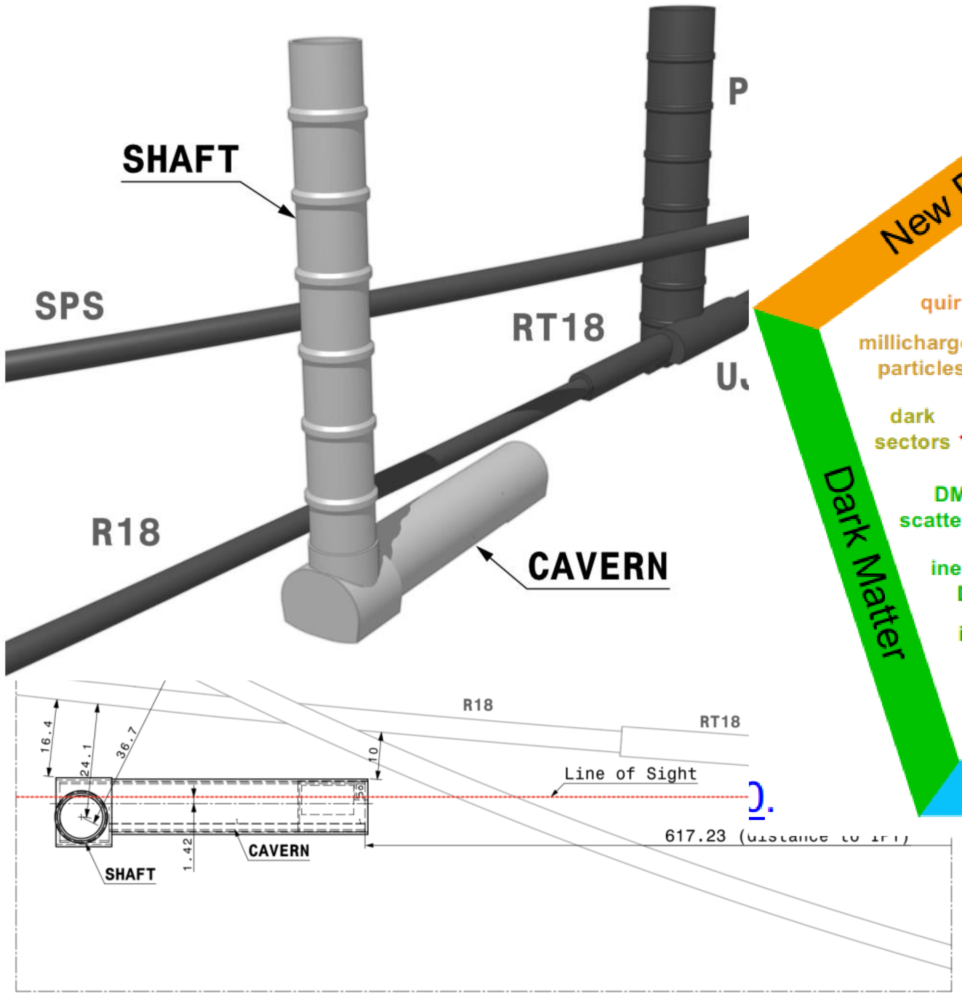
14 Institutes – 60 Participants

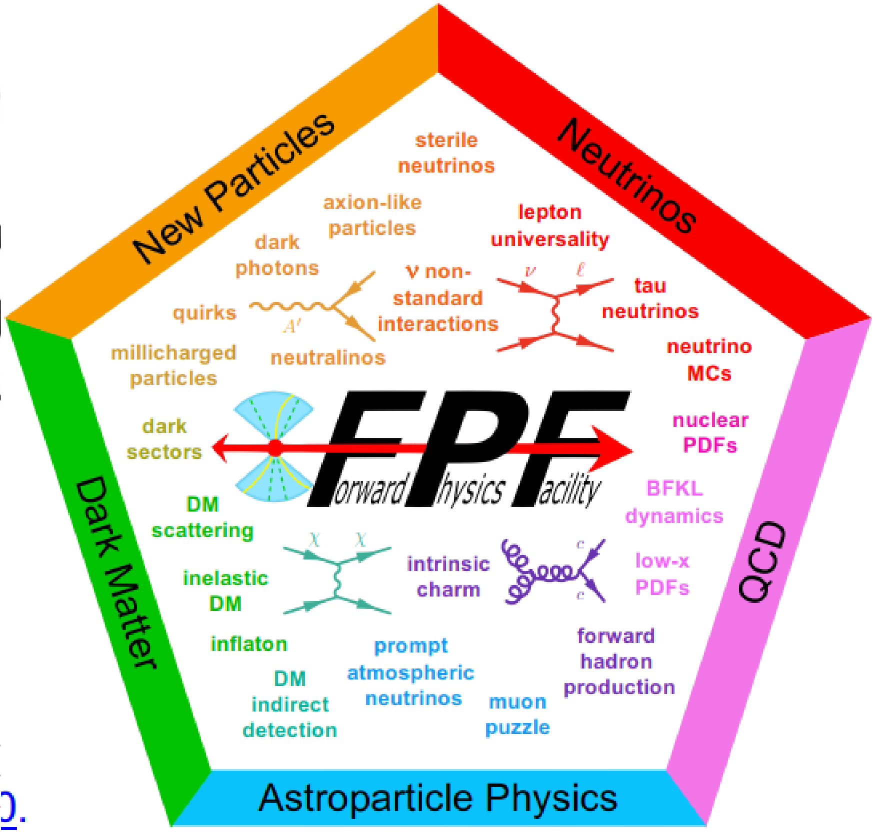
TauFV

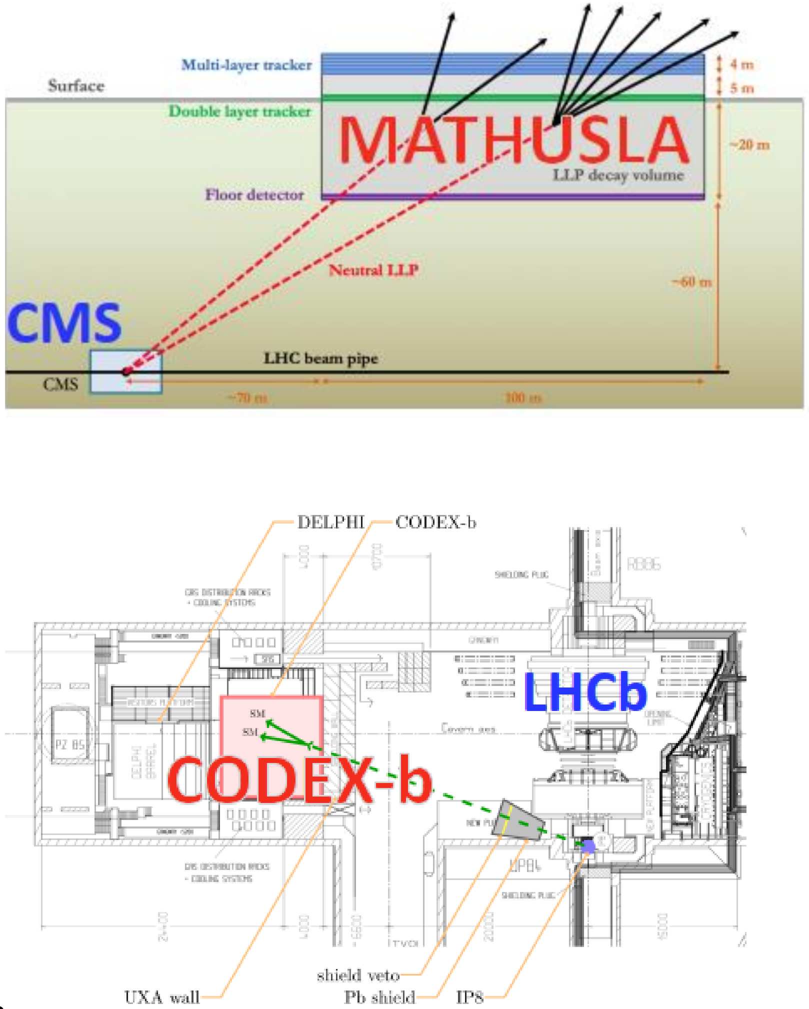
- 9.1 Vector Portal
  - 9.1.1 Minimal Dark Photon model (BC1)
  - 9.1.2 Dark Photon decaying to invisible final states (BC2)
  - 9.1.3 Milli-charged particles (BC3)
- 9.2 Scalar Portal
  - 9.2.1 Dark scalar mixing with the Higgs (BC4 and BC5)
- 9.3 Neutrino Portal
  - 9.3.1 Neutrino portal with electron-flavor dominance (BC6)
  - 9.3.2 Neutrino portal with muon-flavor dominance (BC7)
  - 9.3.3 Neutrino portal with tau-flavor dominance (BC8)
- 9.4 Axion Portal
  - 9.4.1 Axion portal with photon-coupling (BC9)
  - 9.4.2 Axion portal with fermion-coupling (BC10)
  - 9.4.3 Axion portal with gluon-coupling (BC11)

Forward (and transverse) Physics Facility

Search for long-lived particles



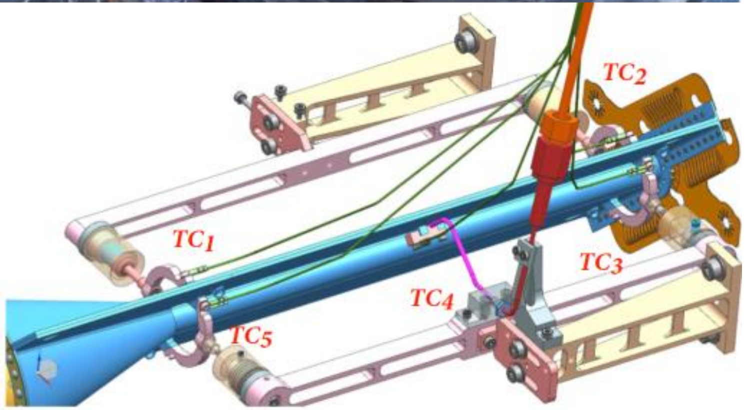


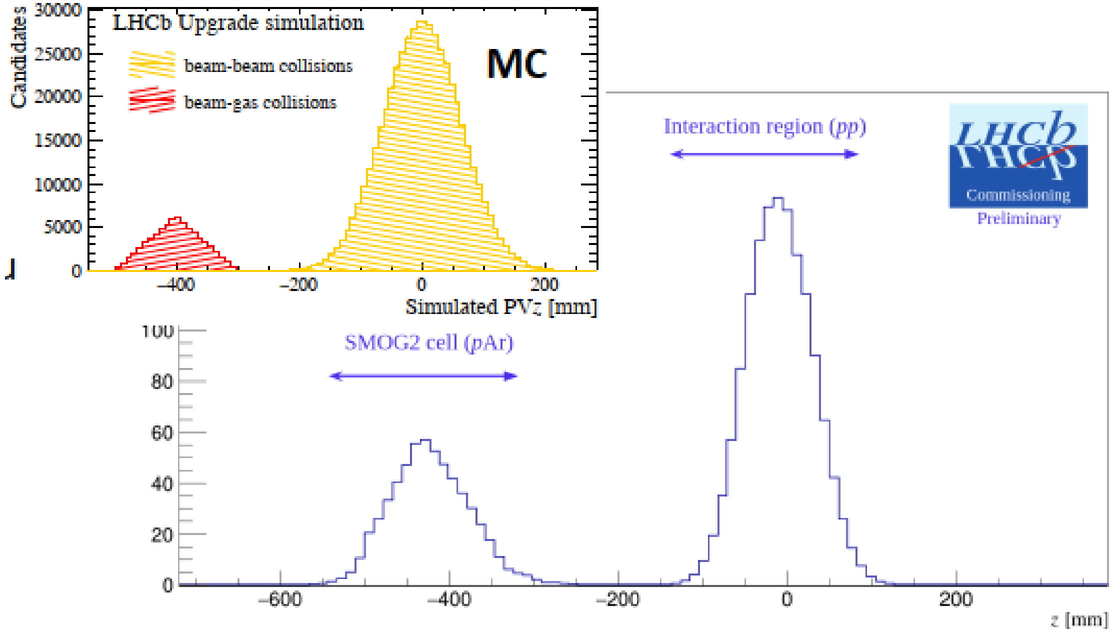


Images sources: J. Boyd, J. Alimena

LHC fixed target: SMOG2

Deep inelastic scattering





- The two interaction regions are clearly visible and well separated!
- PV distributions consistent with simulations
- **LHCb is now the first (unique) LHC experiment with two simultaneous interaction regions!**

Images source: L.Pappalardo

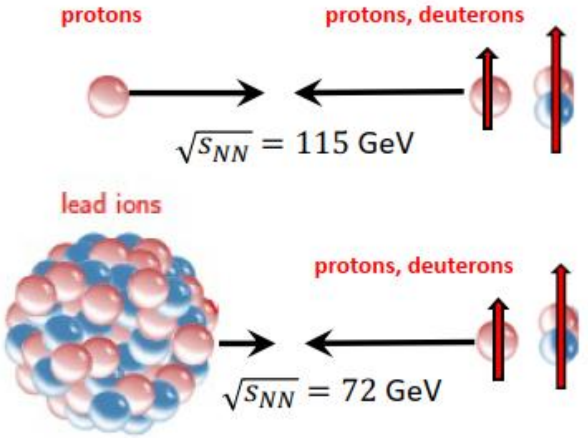
From SMOG2 to LHCspin: polarized gas target

The LHCspin project

SMOG2 is not only a unique project by itself, but also a fantastic playground for the development of a future polarized gas target for LHCb (**LHCspin project**)

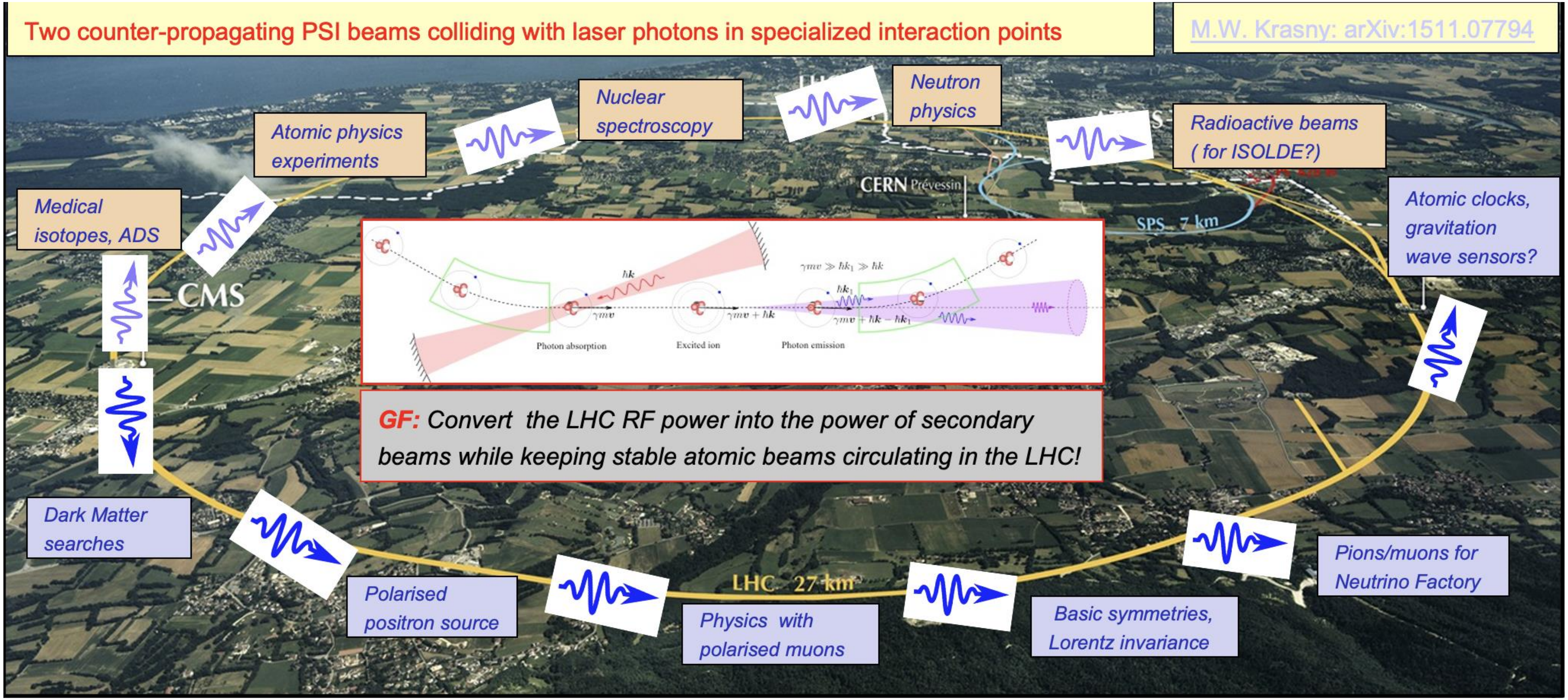
Run 2: **SMOG** → Run 3: **SMOG2** → Run 4 (proposed): **LHCspin**

LHCspin is an R&D project aimed to implement a **new-generation HERMES-like polarized gaseous fixed target** in the **LHCb** spectrometer.



Gamma Factory
(more info here)

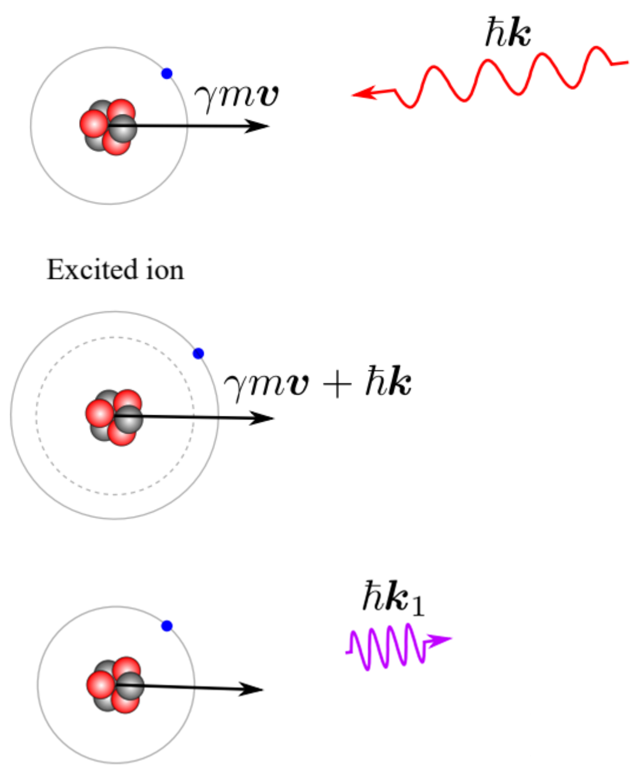
2022 ~ 100 physicists form 40 institutions have contributed so far to the Gamma Factory studies



Gamma factory principle

- Excitation of partially stripped ion at high energy
  - In the ion referential the photon gets a ~2γ boost
  - The change in momentum of the ion is very small

- The excited state is very short lived
  - A photon is spontaneously emitted, isotropically in the referential of the ion
  - The boost back to the rest frame provides another ~2γ boost to forward photons



For instance

Energy upshifting by a factor $4\gamma^2$

→ H-like Xenon at LHC (γ=3000) → 180 MeV

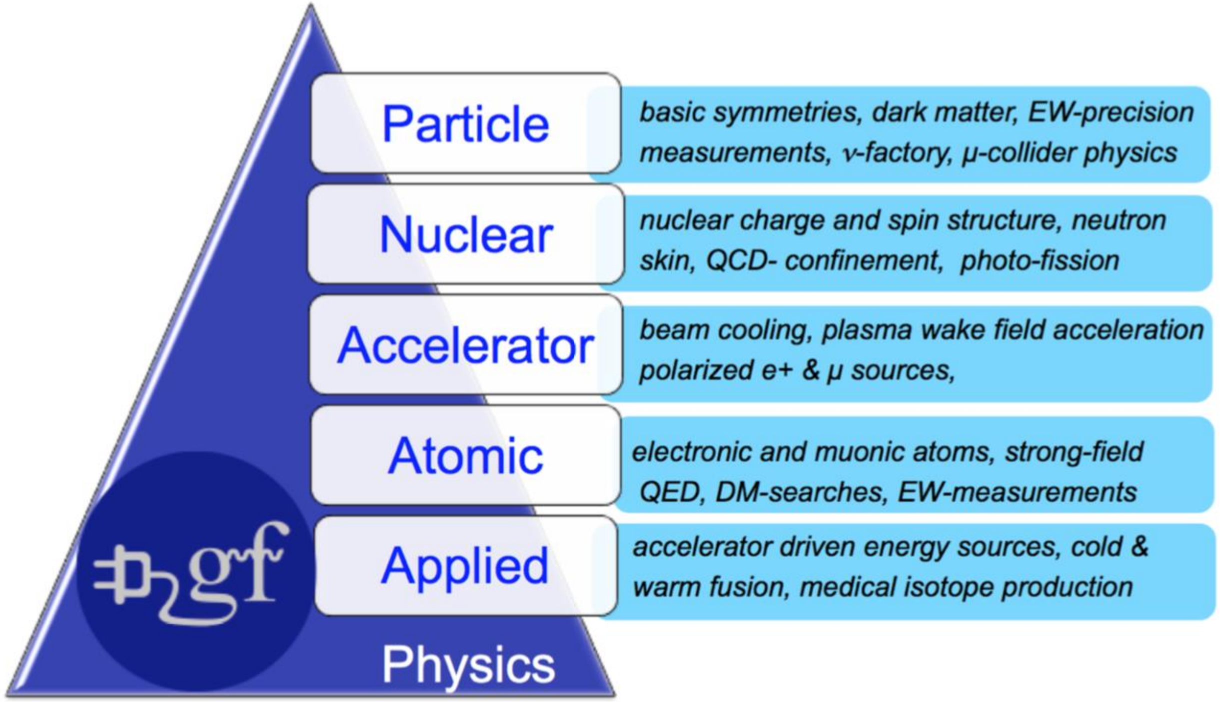
→ Li-like Calcium at SPS (γ=130) → 80 keV

Source: Y. Dutheil

Gamma Factory Physics: almost anything…!

$N_A =$

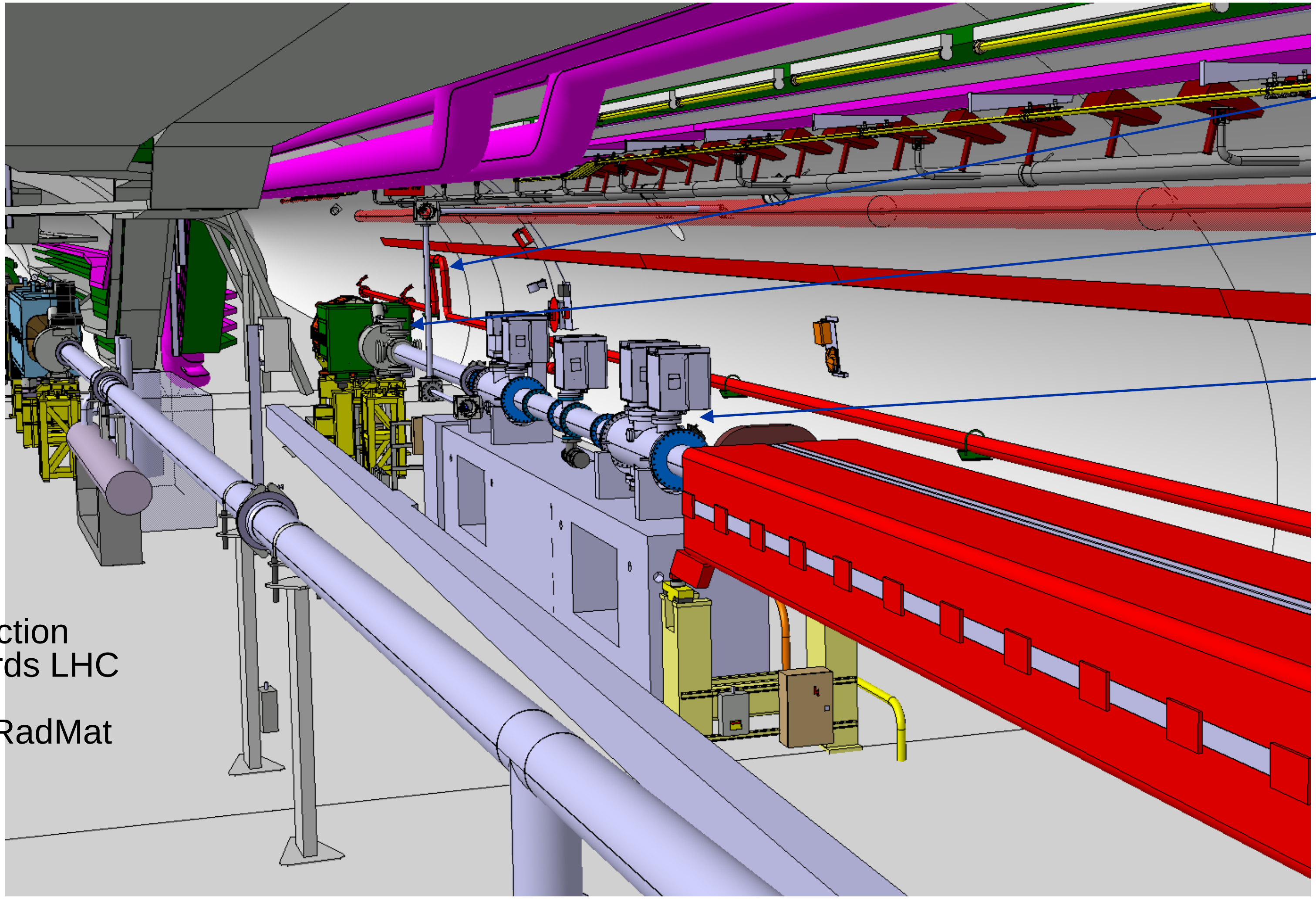
$6{,}023 \cdot 10^{23}$



Nγ/day = 5.4 x10^23

Source: M.W. Krasny

SPS Proof-of-Principle: preparation in LS3 for Run 4

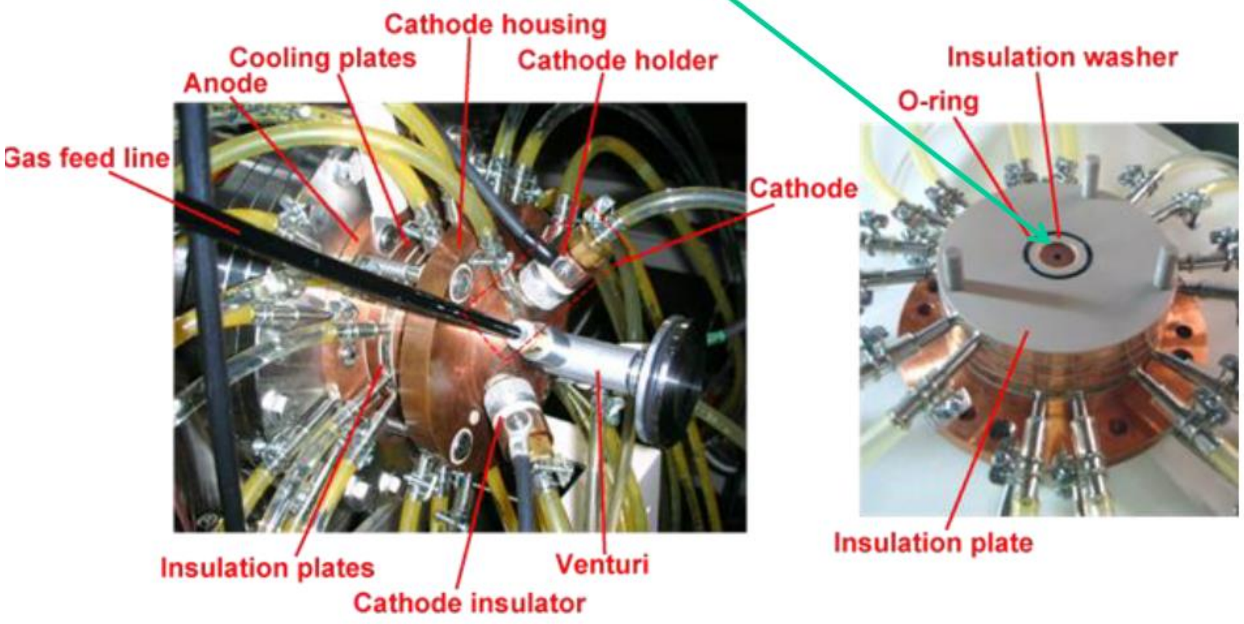


Source: Y. Dutheil

How to make a vacuum window to allow gammas through without interactions?

REKIN (RIBF) Plasma Window

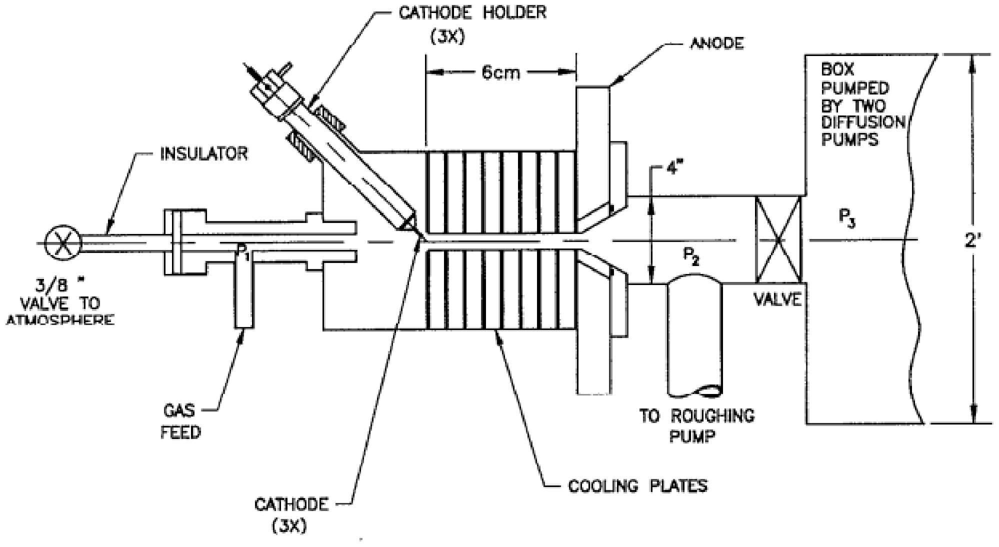
(empty hole becomes window when filled with plasma)



High-pressure arcs as vacuum-atmosphere interface and plasma lens for nonvacuum electron beam welding machines, electron beam melting, and nonvacuum ion material modification

Ady Hershcovitch
AGS Department, Brookhaven National Laboratory, Upton, New York 11973-5000

(Received 18 April 1995; accepted for publication 25 July 1995)



The PBC Technology Working Group

More information: Website , Workshops

From the Technology WG mandate

- …explore and evaluate possible technological contributions of CERN primarily to non-accelerator-related experimental physics initiatives and projects that may also be hosted elsewhere
- …survey technologies that could become relevant to CERN accelerator and non-accelerator projects
- …favour the exchange of experience and expertise in technological domains such as superconducting and normal conducting magnet and RF technology, cryogenics, optics, vacuum and surface technology
- …support the development of new physics experiments and detection methods like quantum sensing and new (accelerator and non-accelerator) experiment proposals

Experiments & proposals linked with Tech WG

- **ALPS-II / Jura → Data taking at DESY**
- **babyIAXO → Experiment at DESY, collaboration agreement with CERN**
- **Grenoble Haloscope (GrAHal) → will apply to REC**
- **VMB@CERN → will apply to SPSC**
- **DarkSide**
- **Ptolemy- Carbon NanoTubes**
- **STAX**
- **Advanced-KWISP**
- **RADES/HTS**
- **Axion Heterodyne Detection**
- **AION-100 @ CERN**

In development in other laboratories with CERN support (DarkSide, Ptolemy- Carbon NanoTubes, STAX, Advanced-KWISP)

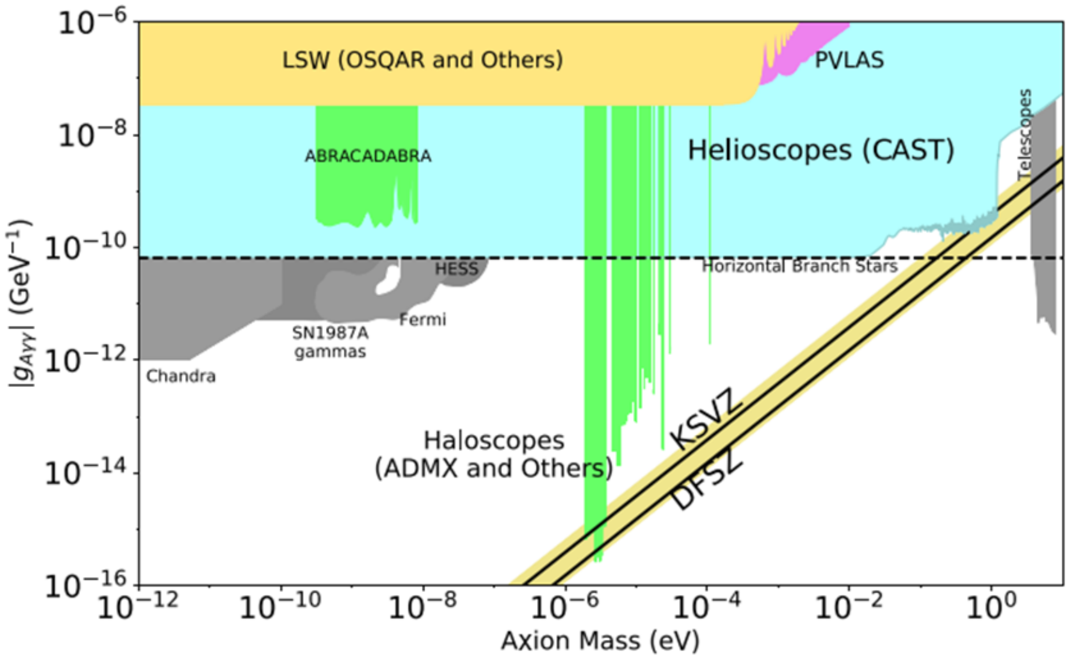
In development at CERN (RADES/HTS, Axion Heterodyne Detection, AION-100 @ CERN)

Axion as dark matter candidate

Electron mass = 511 keV
Proton mass = 938 MeV

Axion mass = … ?? …

- **Many candidates, many theories.**
  - Interaction mainly by gravity
  - Very weak interactions with all other types of particles (baryons, electrons, photons…)
- **Axion is the best dark matter candidate**
- **Axion are also the solution to the strong CP problem**

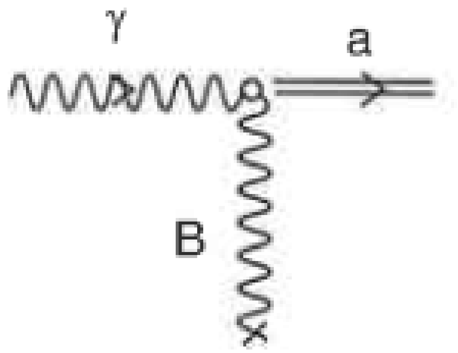


Source: review of particle properties

Two major families of experiments

Direct conversion in a magnetic field – Primakoff effect

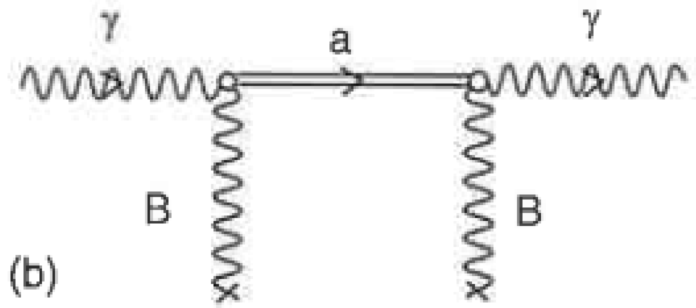
- **An axion may convert a magnetic field into a photon – RF signal**



- **Detected in cavities immersed in a magnetic field**

Vacuum birefringence - light shining through a wall

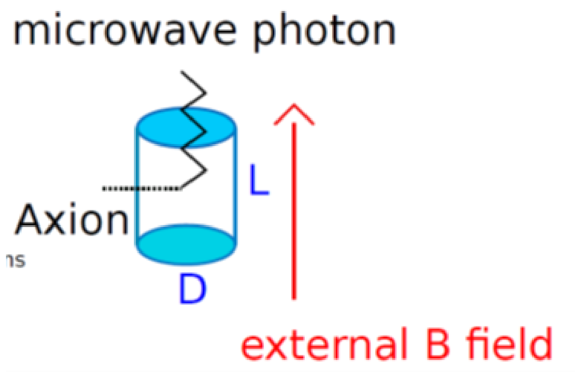
- **A magnetic field and a photon interact and create an axion – which travels and recreates a photon**



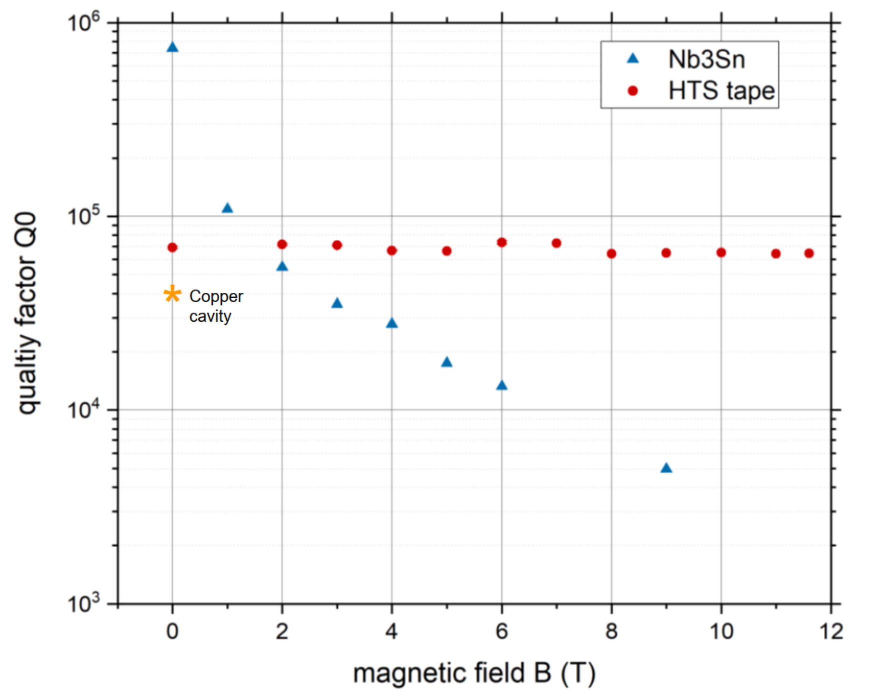
- **Seen as a change of polarization, or light appearing behind a wall**

Source: S. Asztalos

The RADES experiment
RADES: Relic Axion Detector Exploratory Setup



Tested in SM18 in 11.5 T dipole



Nb_3Sn ≈ 2 µm layer

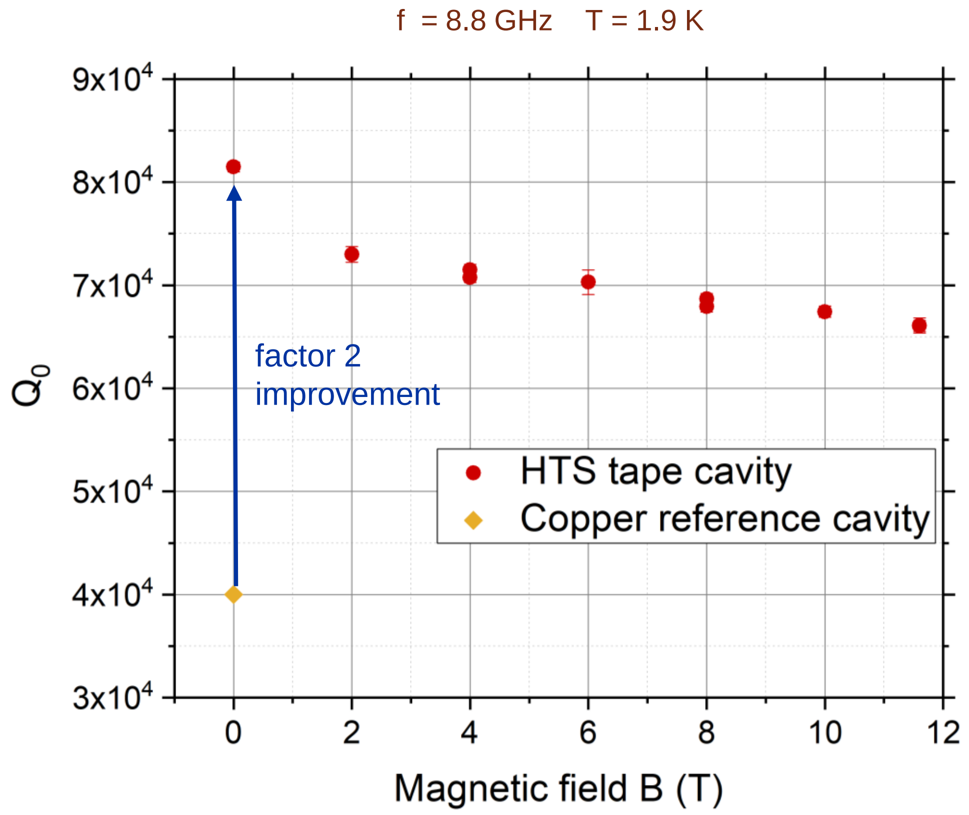
Coated at CERN by G. Rosaz and C. Pereira Carlos

HTS tape

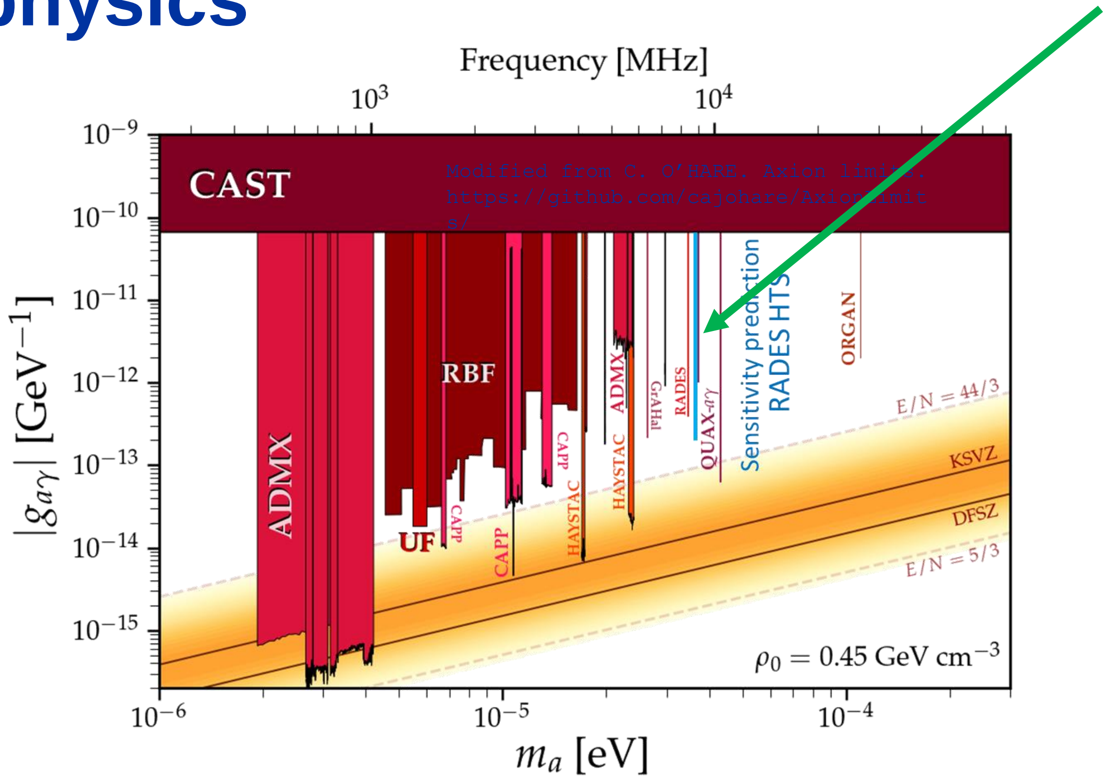
Tape attached at ICMAB by G. Telles, N. Lamas, X. Granados, T. Puig, J. Gutierrez

Source: J. Golm

RADES results
A simple experiment expanding physics



$$\mathcal{F} \sim g_{A\gamma}^{4}\, \boldsymbol{Q}\, T_{sys}^{-2} V^{2} G^{4} m_{A}^{2}\, \boldsymbol{B}^{4}$$



- Data taking with RADES HTS cavity performed in 11 T magnet (Grant Agreement No 730871(ARIES-TNA))
- Results are currently being analysed by S. Arguedas Cuendis

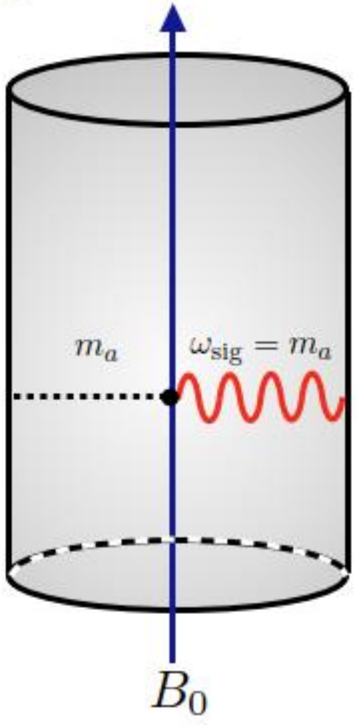
Source: J. Golm

Axion heterodyne detection
Using SRF cavity and not a magnet

Static-field Haloscope:

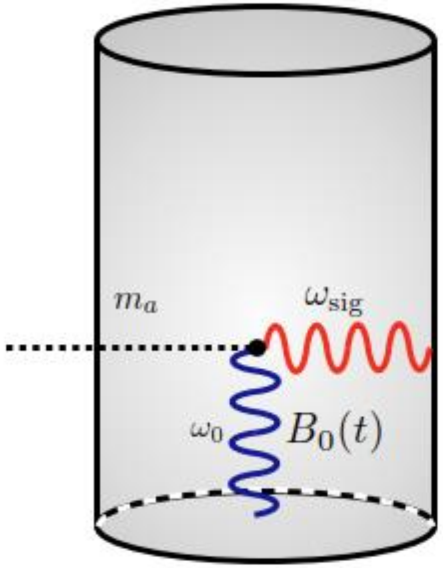
e.g. ADMX

$$\omega_{\rm sig} = m_a \sim V^{-1/3}$$



Heterodyne Resonator:

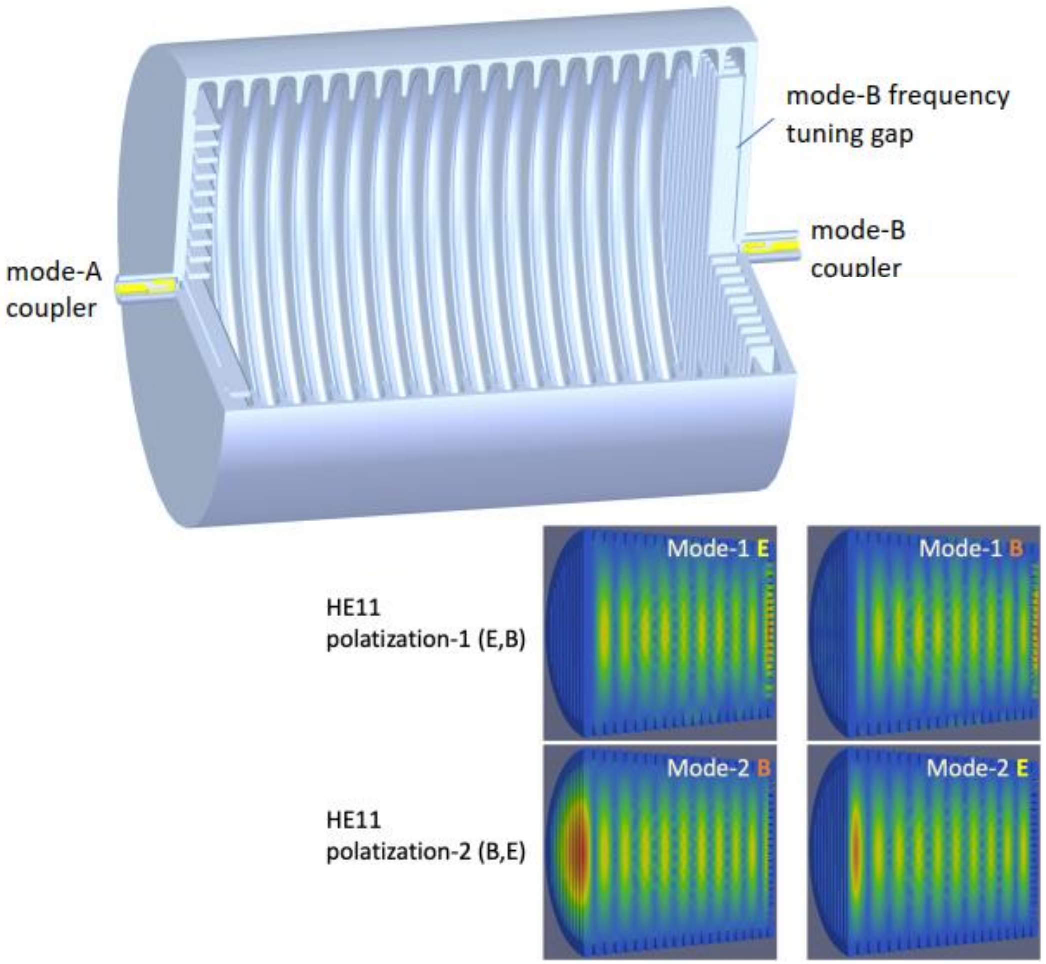
$$\omega_{\rm sig} \sim \omega_0 \pm m_a \sim V^{-1/3}$$



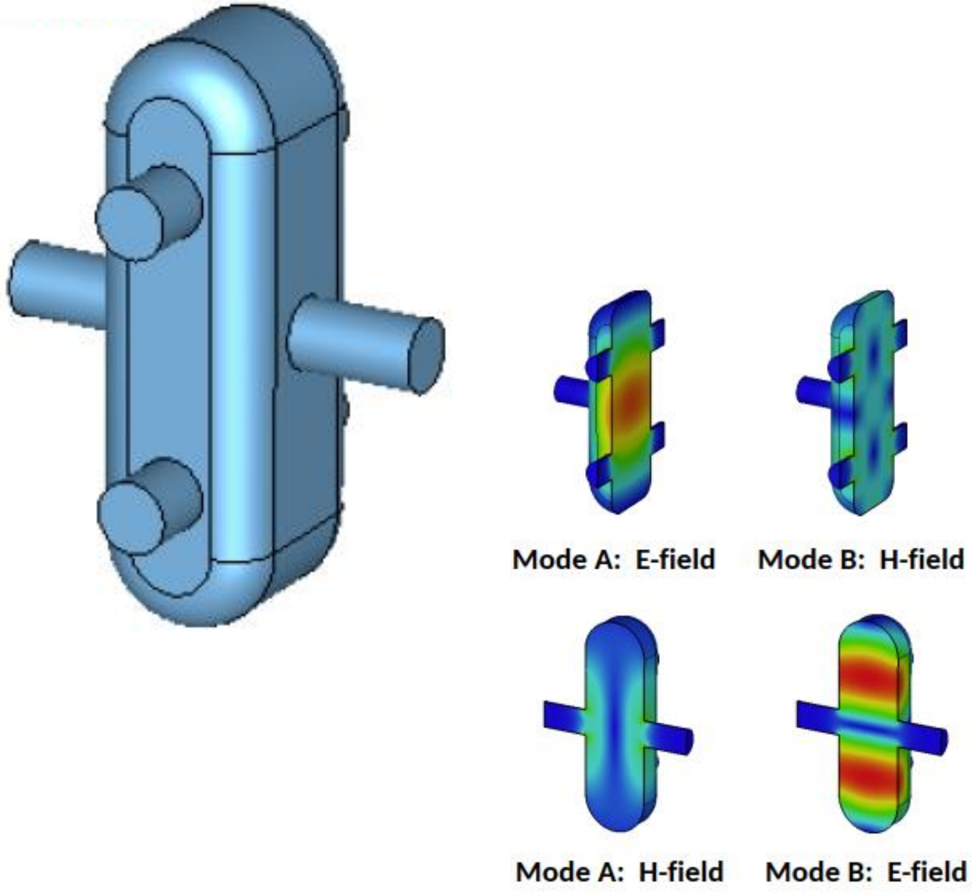
JHEP 07 (2020) 088, hep-ph/1912.11048
A. Berlin, R. T. D'Agnolo, SARE, P. Schuster, N. Toro, C. Nantista, J. Neilson, S. Tantawi, K. Zhou

Source: S. Ellis

Cavity designs: pushing SRF technology to its limit
Nb/Cu coating? EP?



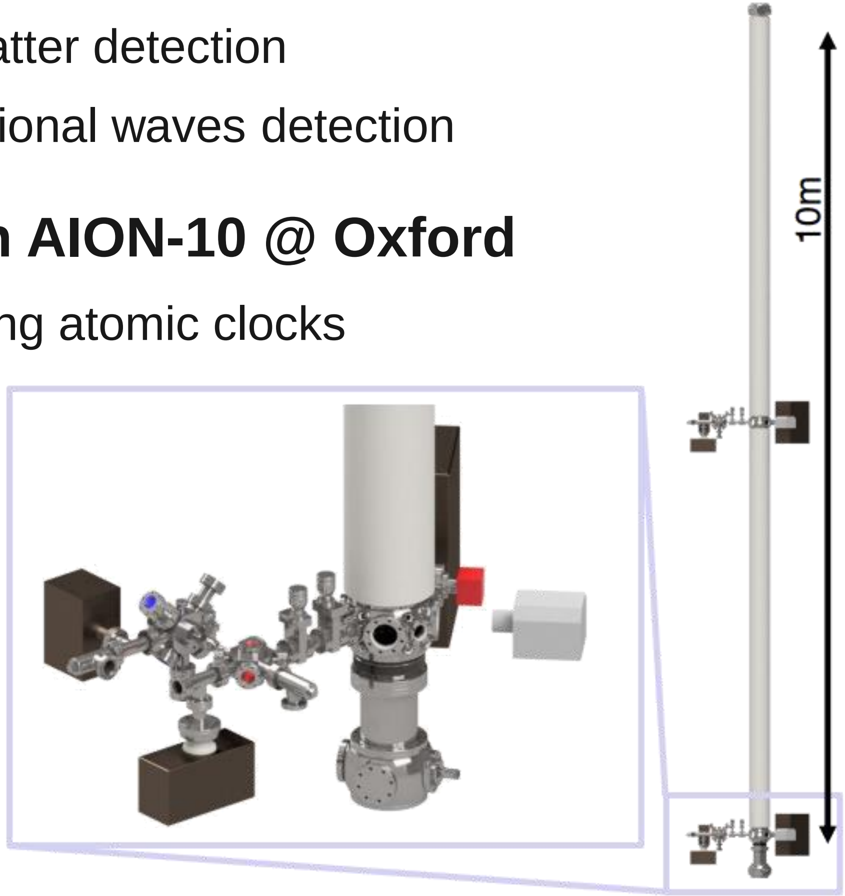
Source: Zenghai Li



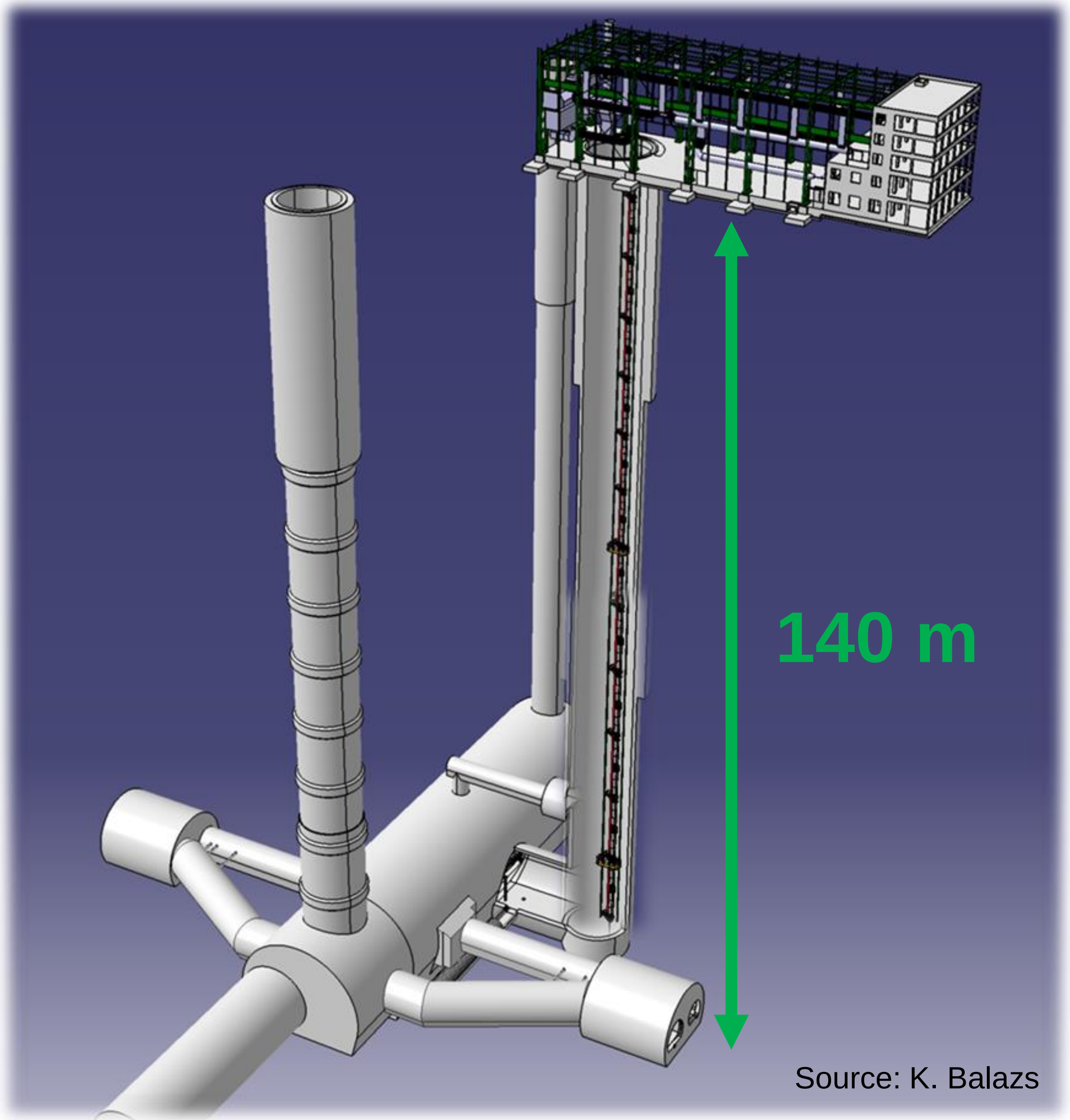
Source: A. Macpherson

Long-baseline atom interferometry in PX 46

- **AION-100 @ CERN proposal**
  - Dark matter detection
  - Gravitational waves detection
- **Based on AION-10 @ Oxford**
  - Interfering atomic clocks



Source: J. Ellis



Source: K. Balazs

Conclusions

- **The Physics Beyond Collider activity aims at using the huge potential of CERN infrastructure, technologies, and peoples' competencies, to promote novel experiments at the frontier of particle physics**

- **These experiments have often a great trade off in terms of cost versus physics potential**

- **Nevertheless, PBC also encompasses visionary projects defying the state of the art of accelerator technologies**

- **PBC helps moving from the idea and feasibility stage to being CERN recognized projects or experiments. Many succeeded already, several are in the pipeline. Stay tuned!**

CERN-PBC Report-2022-xxxx

author.email@cern.ch

AION-100 @ CERN: Feasibility Study

G. Arduini, K. Balazs, S. Calatroni, ... (to be finalized).

Abstract

AION-100 @ CERN will be beautiful.

home.cern