CERN

Physics Beyond Colliders

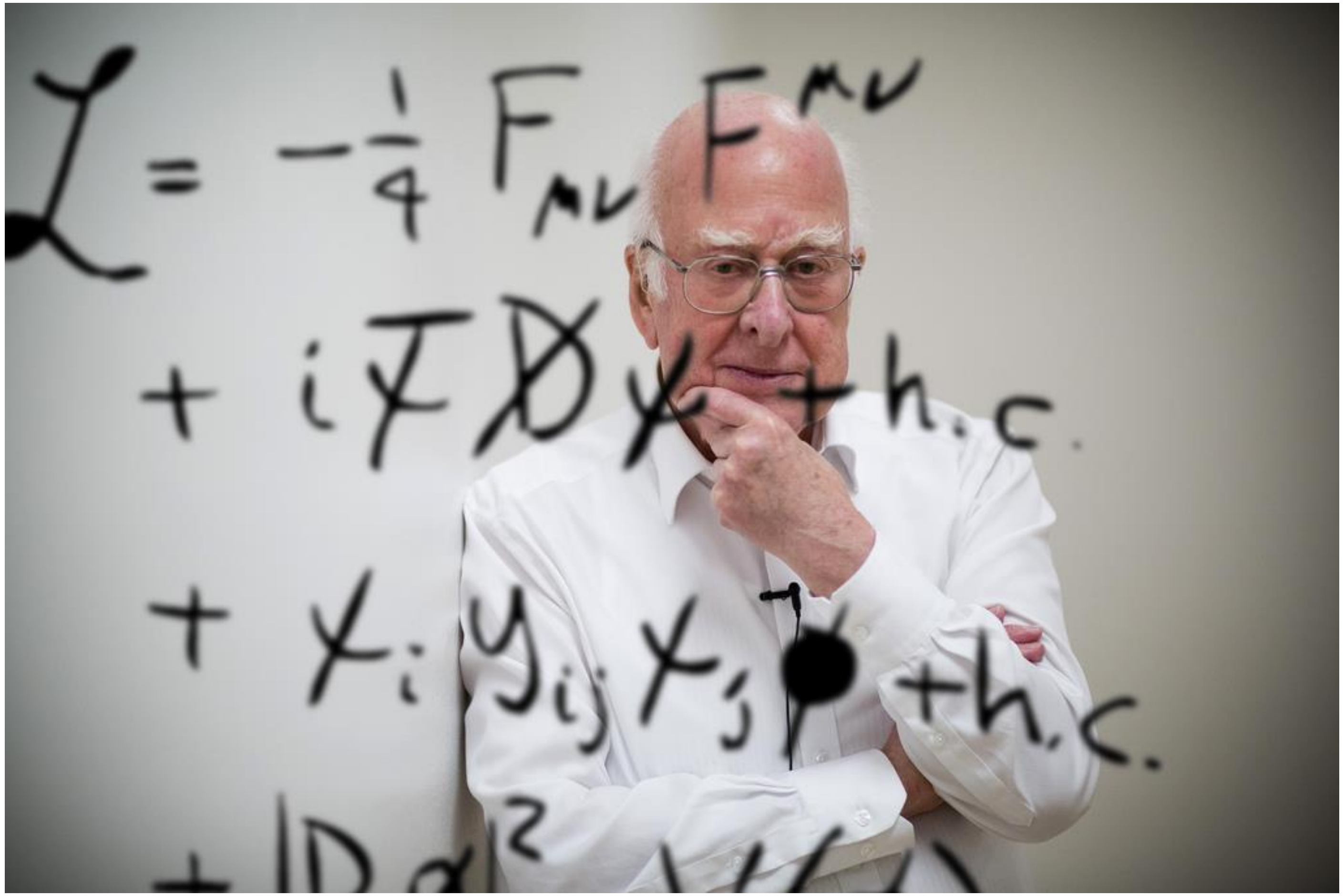
Physics Beyond Colliders is an exploratory study aimed at exploiting the full scientific potential of CERN's accelerator complex and its scientific infrastructure through projects complementary to the LHC, HL-LHC and other possible future colliders.

Mike Lamont, Jörg Jaeckel, Claude Vallée on behalf of the PBC studies teams

8th June 2018

Acknowledgements: G. Lanfranchi, S. Gori

Beyond Standard Model (BSM)



– 19 free parameters;
– neutrino masses;
– dark matter;
– origin of the matter-antimatter asymmetry;
– dark energy;
– inflation;
– gravity.

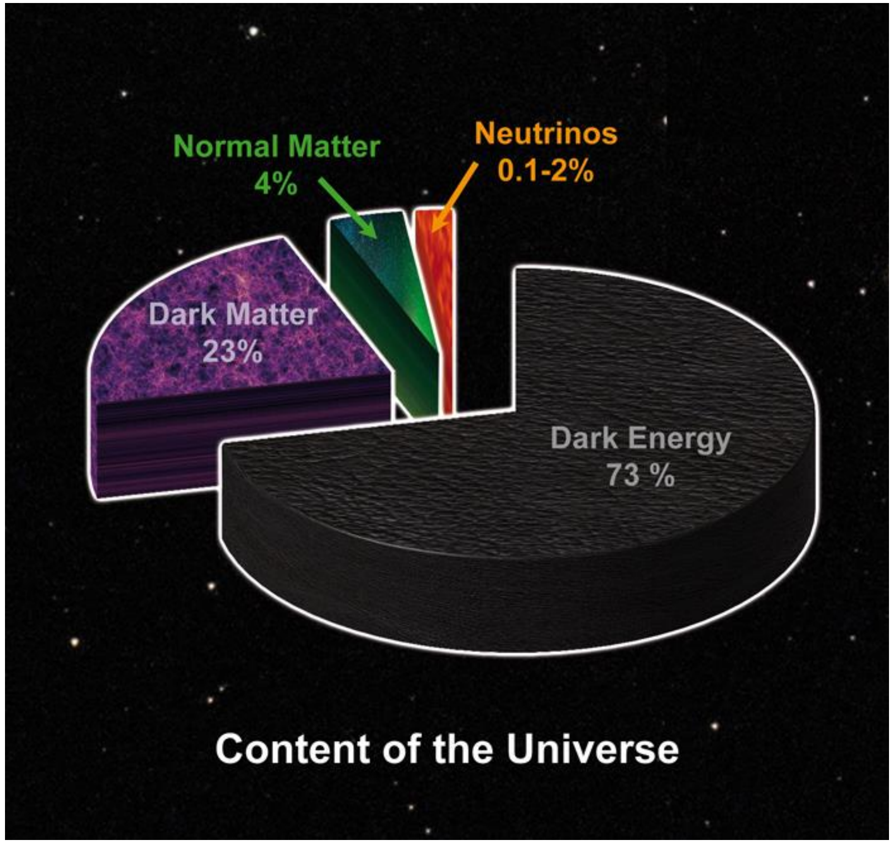
The case for BSM physics is compelling

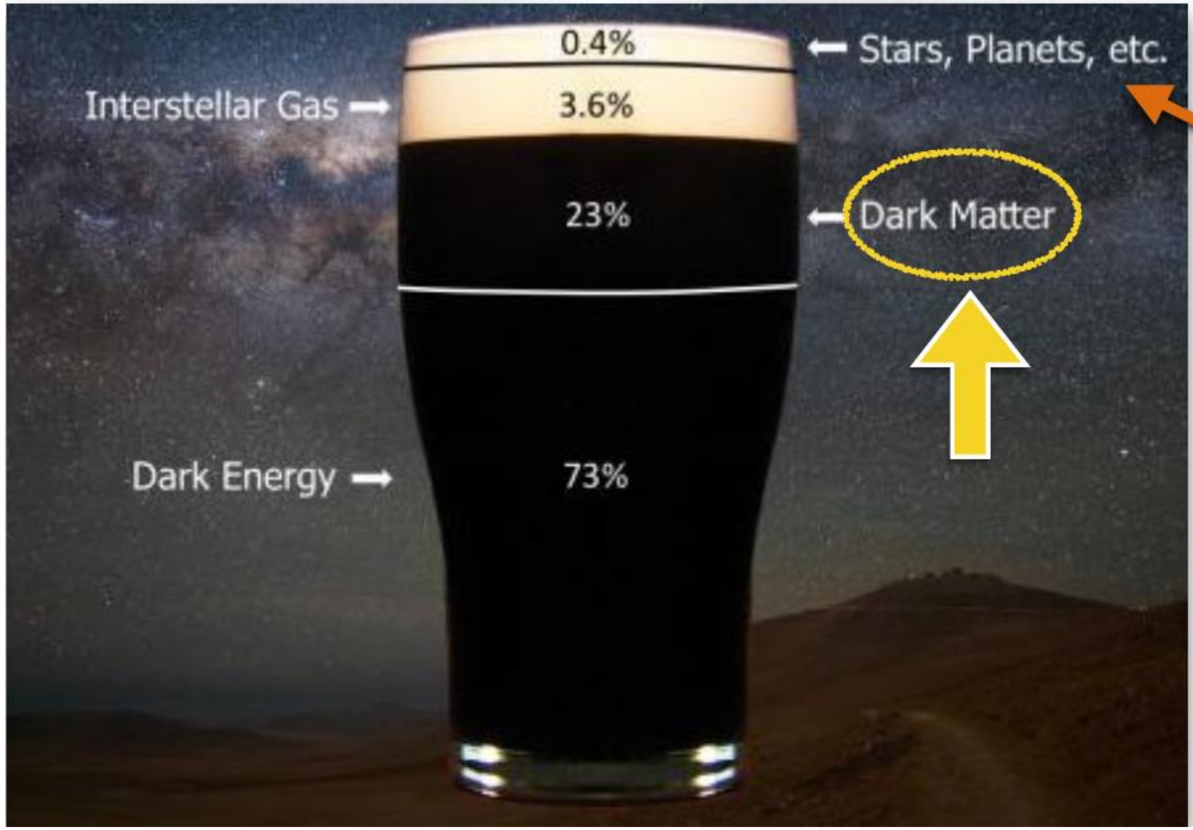
The last weasel that doubted that there is Physics Beyond the Standard Model

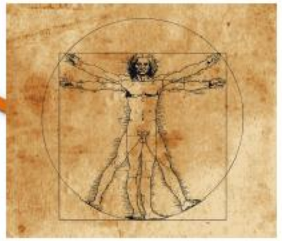
The Cern stone marten, secured for inclusion in the Rotterdam Natural History Museum's Dead Animal Tales exhibition. Photograph: Kees Moeliker

From The Guardian website

Dark Matter





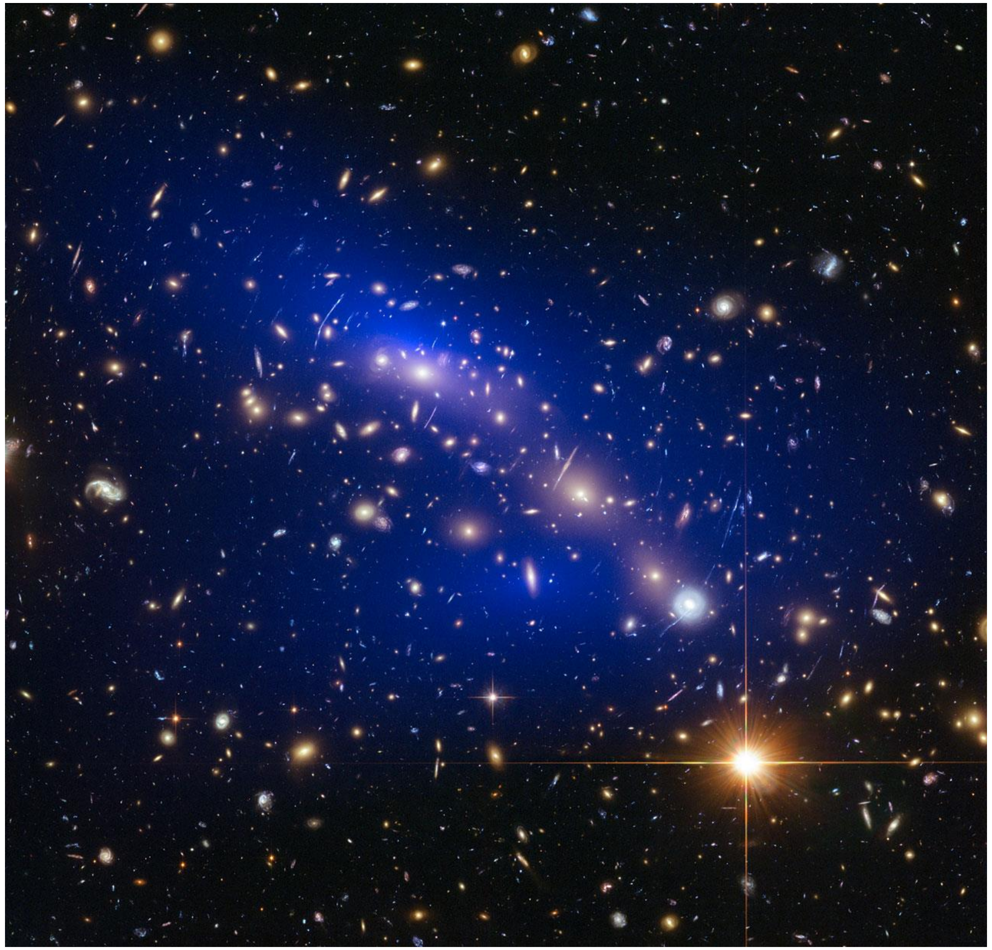


us

Stefania Gori

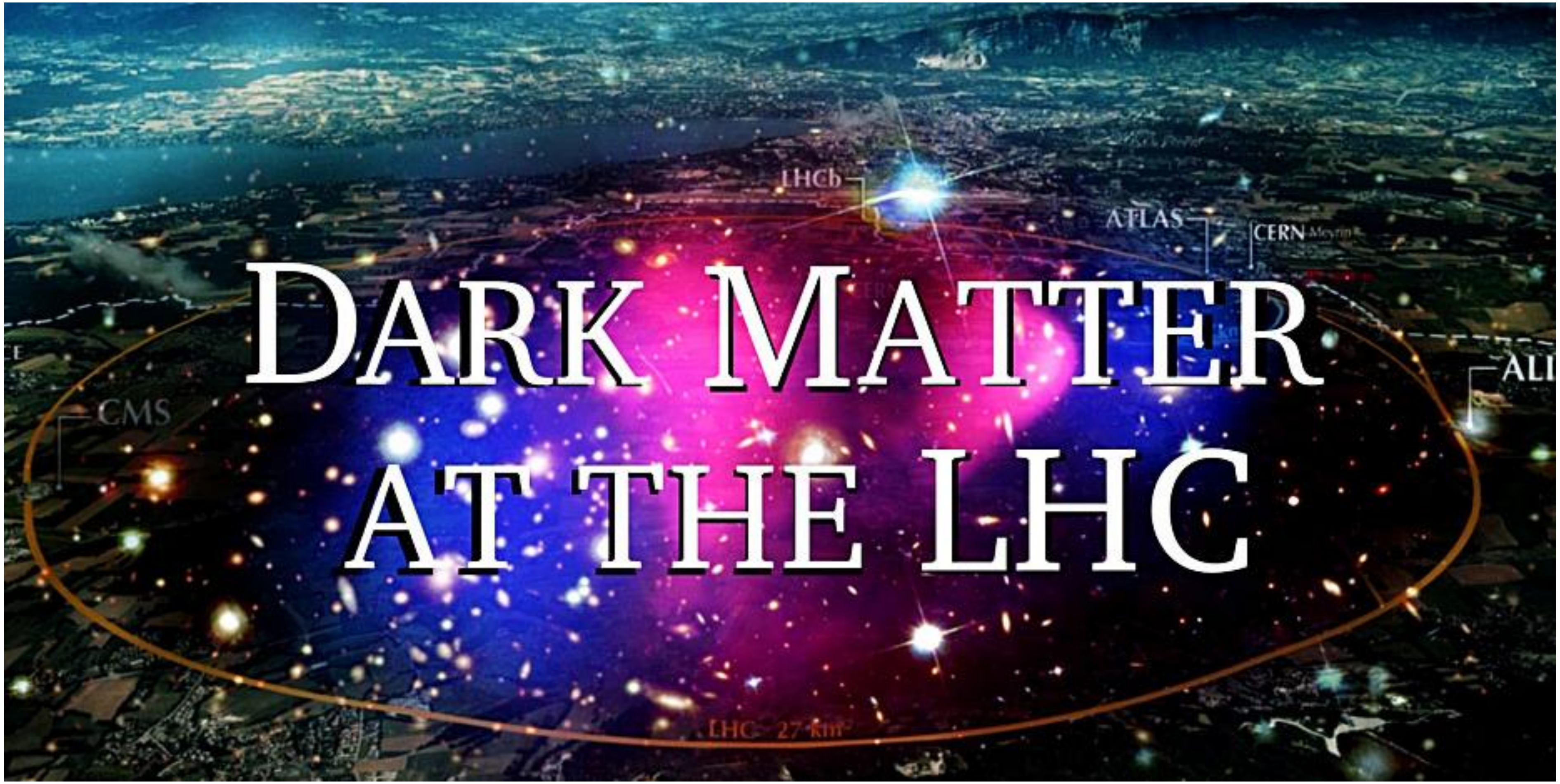
Dark matter – we know…

- Is roughly 80% of the matter in the universe.
- Has mass (and hence gravity).
- Doesn’t scatter/emit/absorb light (really “transparent matter”)
- Interacts with other particles weakly or not at all (except by gravity).
- Is distributed through galaxies and the universe in a way that we can predict and map.



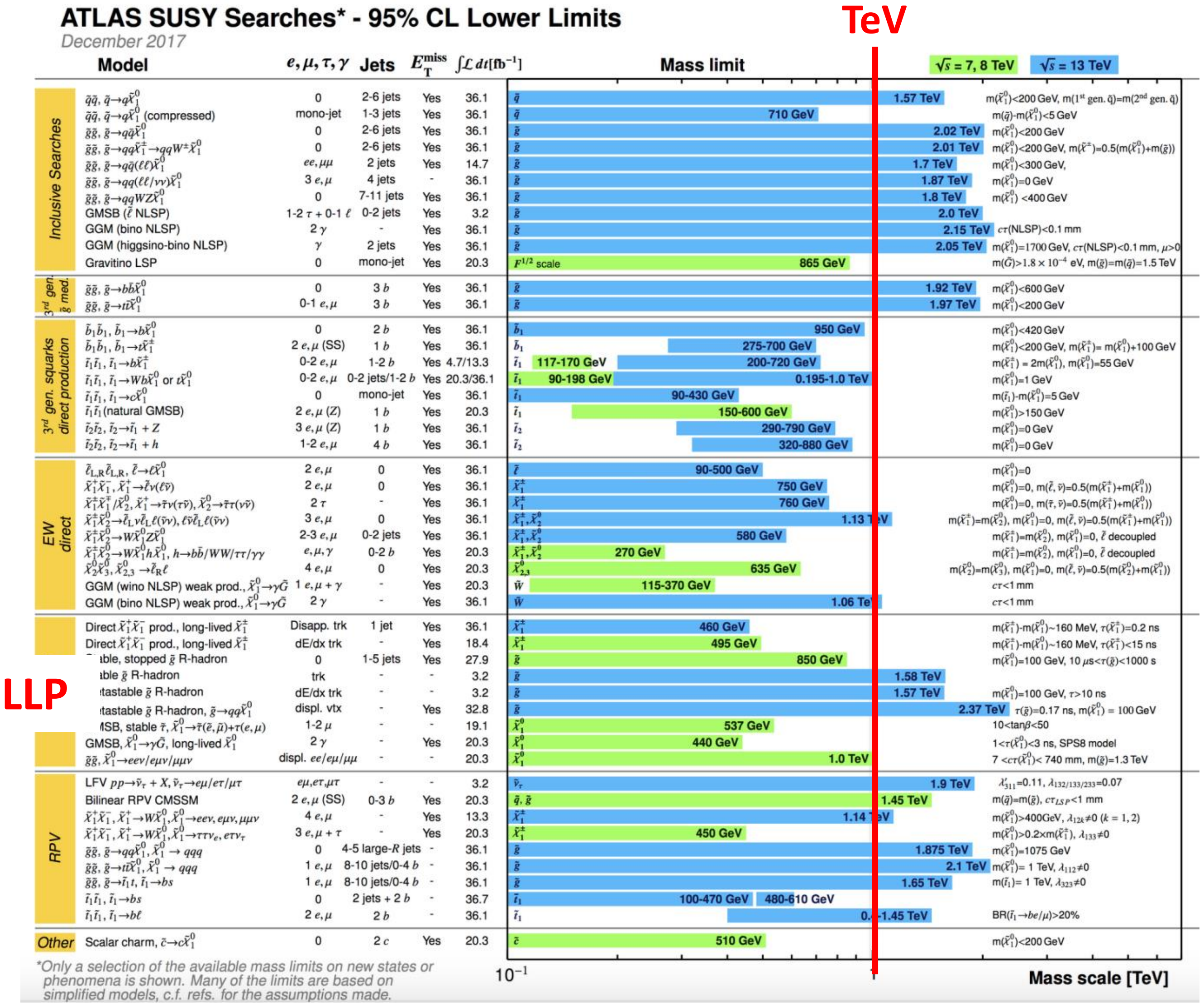
Galactic rotation curves, galaxy clusters, galaxy lensing, CMB…

Dark Matter: make it



Nothing at the LHC yet

So far, no *conclusive* signal of physics beyond the SM



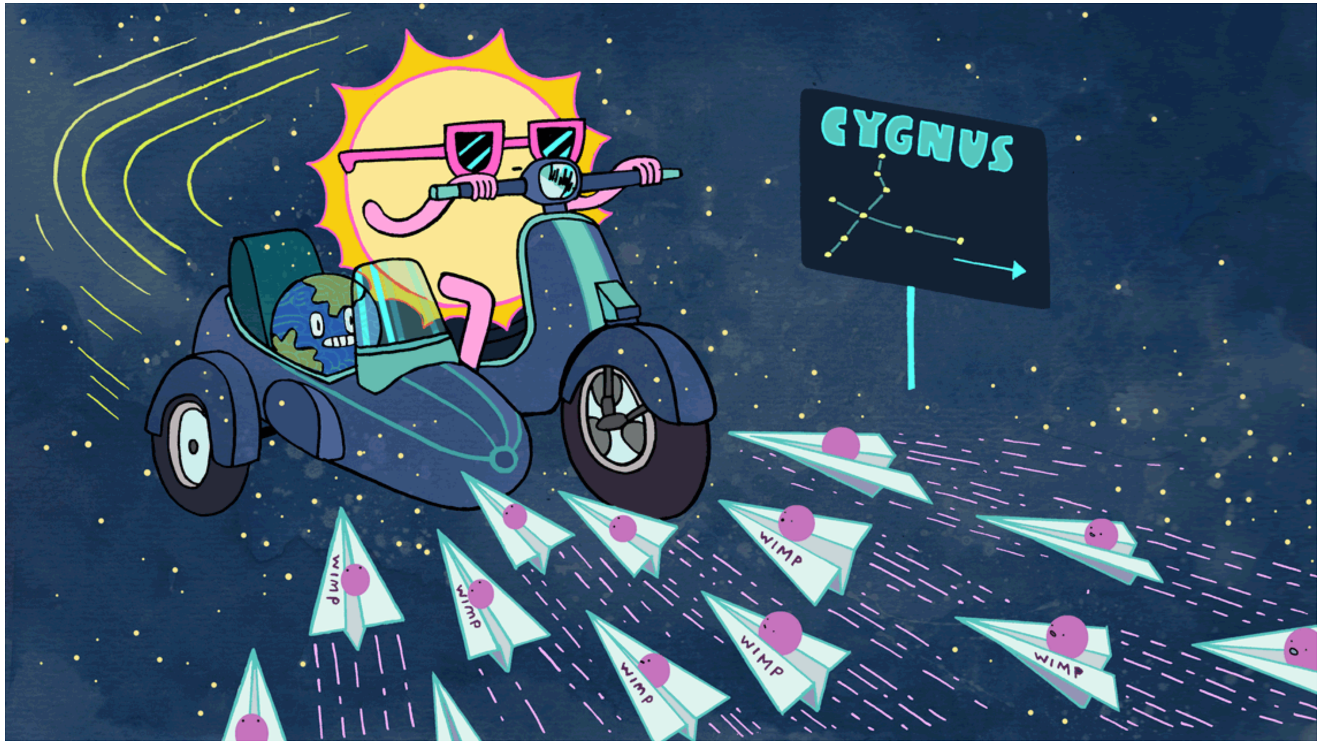
Collider physicists are looking everywhere.
So far, no evidence of dark matter… but they haven't given up.

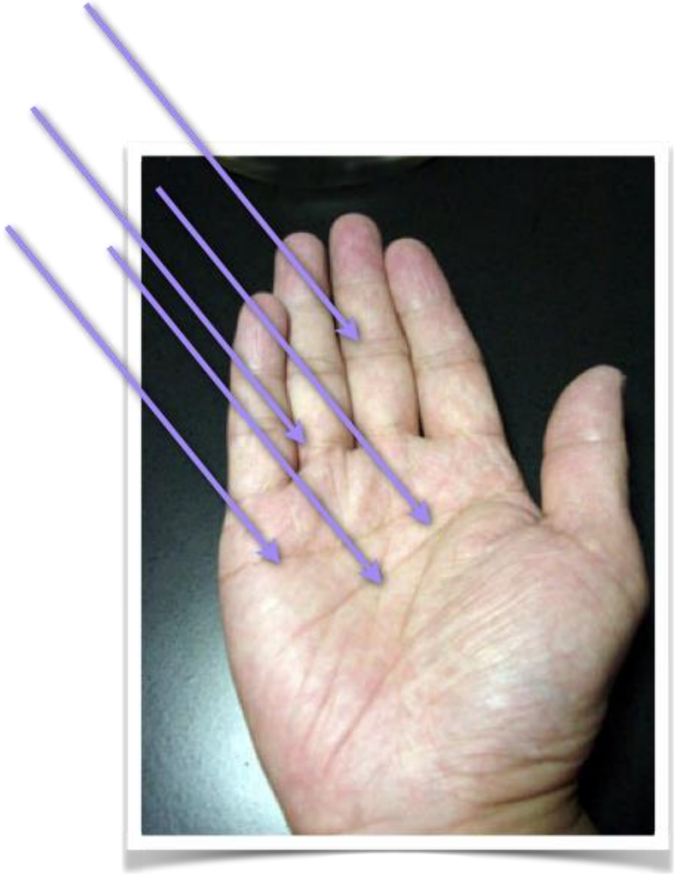
Higgs discovered with mass ~125.5 GeV.

No new particles found.

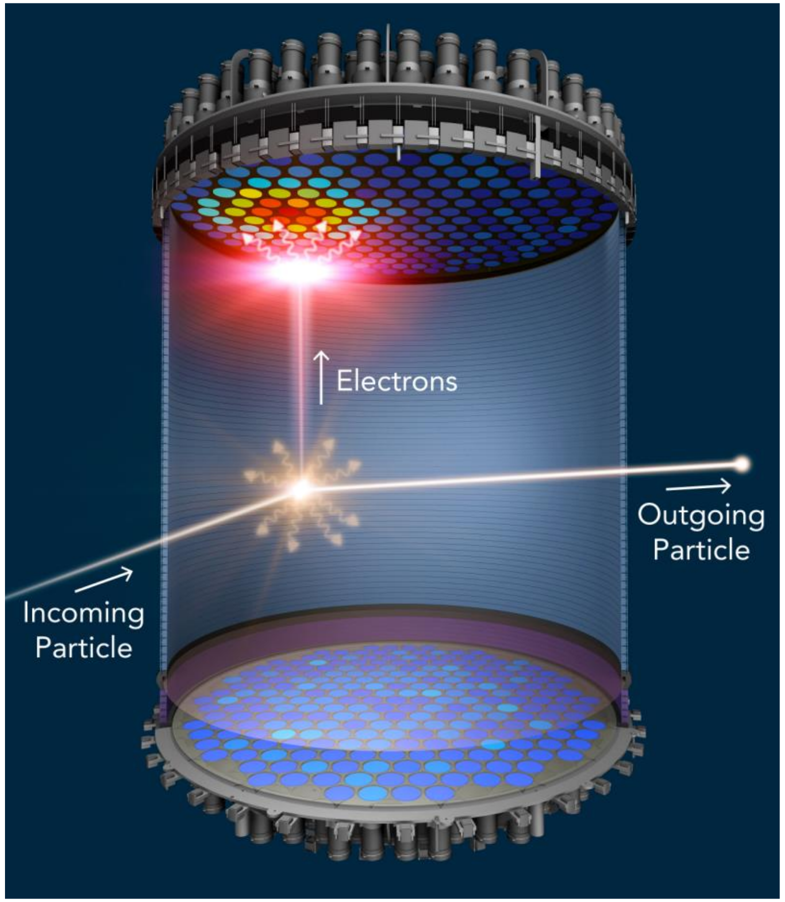
Dark Matter: shake it

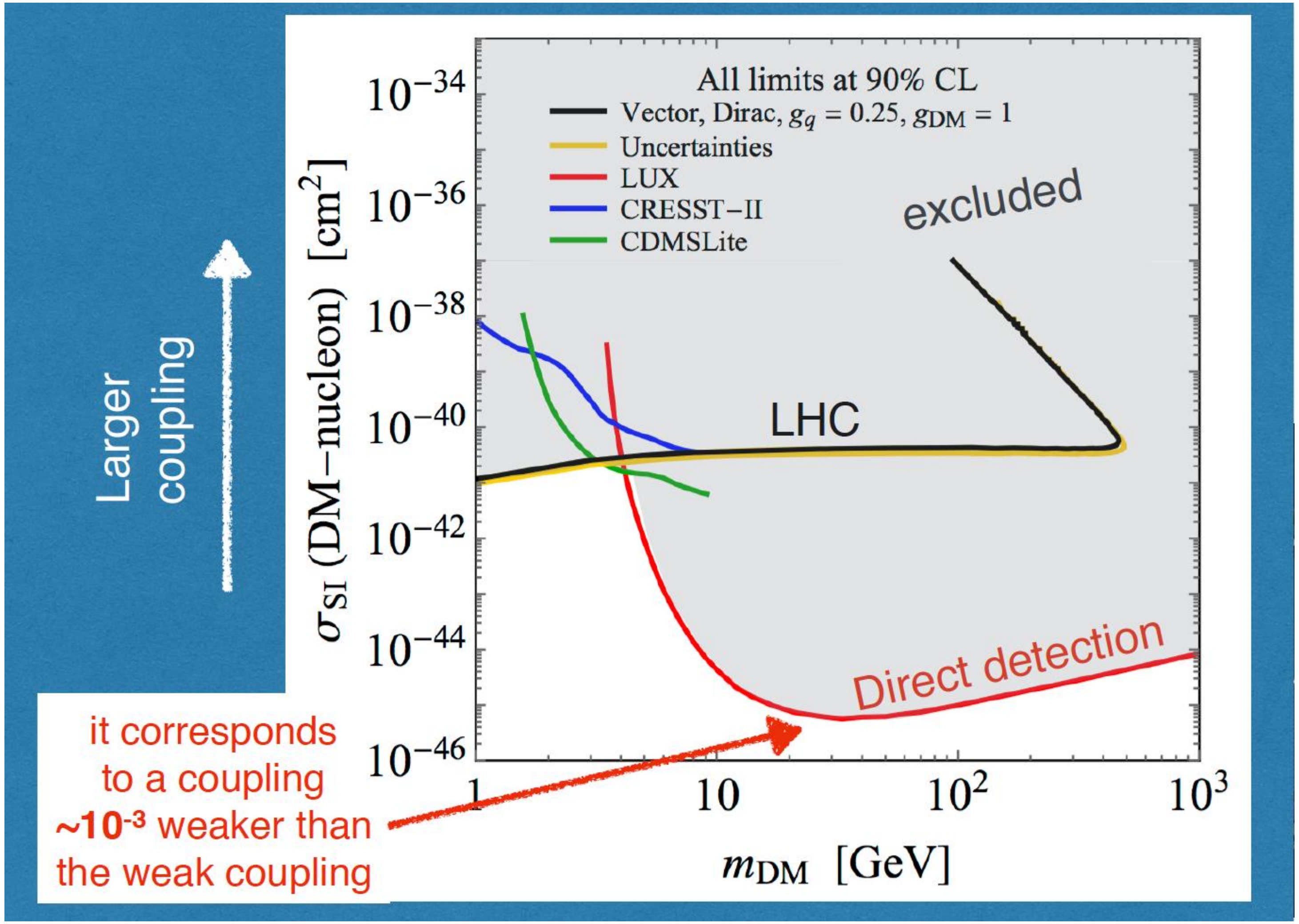
- Dark Matter exists in a halo around our galaxy.
- Our speed relative to the dark matter halo is ~220 km/s.
- If the dark matter is a weakly-interacting massive particle (WIMP), ~ 10 million would go through a hand each second.





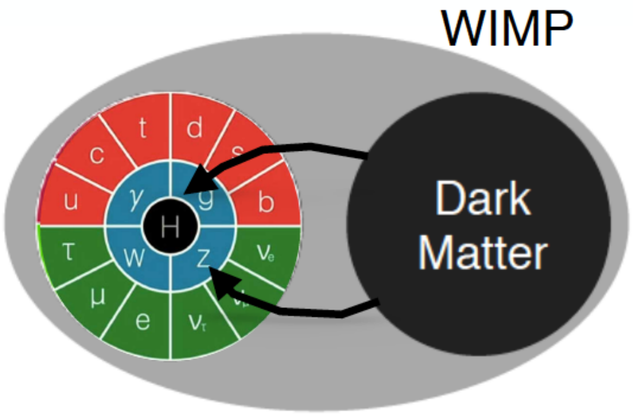
Direct detection – WIMP searches





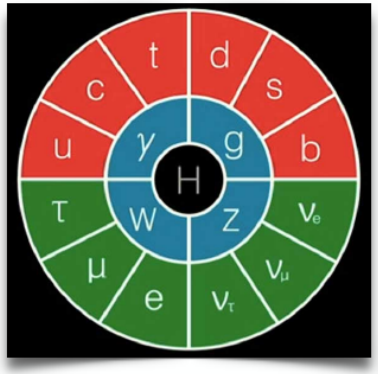
Again – nothing yet

Life beyond WIMPs: dark sectors

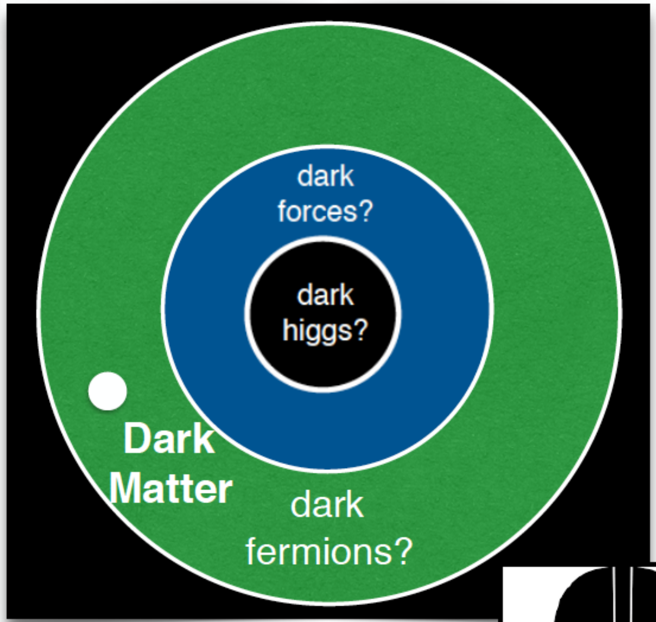


Minimality

versus



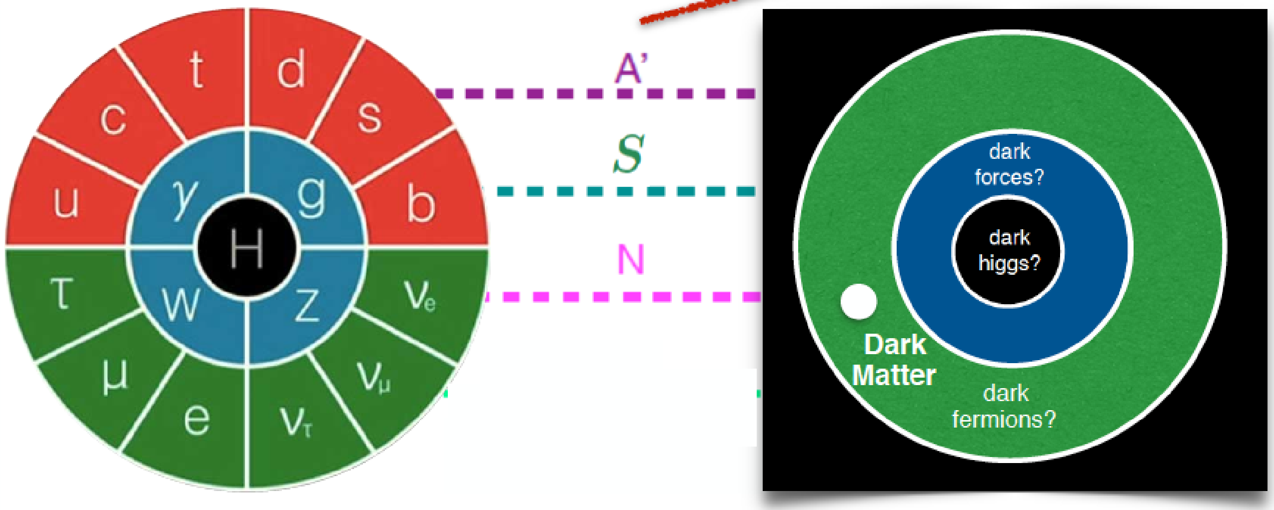
The “dark sector”



Plentitude

Easier to have lighter (< 100 GeV) DM

Portals



Not charged under the SM gauge symmetries

"Portals":

Dark photon	$\epsilon Z^{\mu\nu} A'_{\mu\nu}$
Higgs	$\kappa \lvert H \rvert^2 \lvert S \rvert^2$
Neutrino	$y H L N$

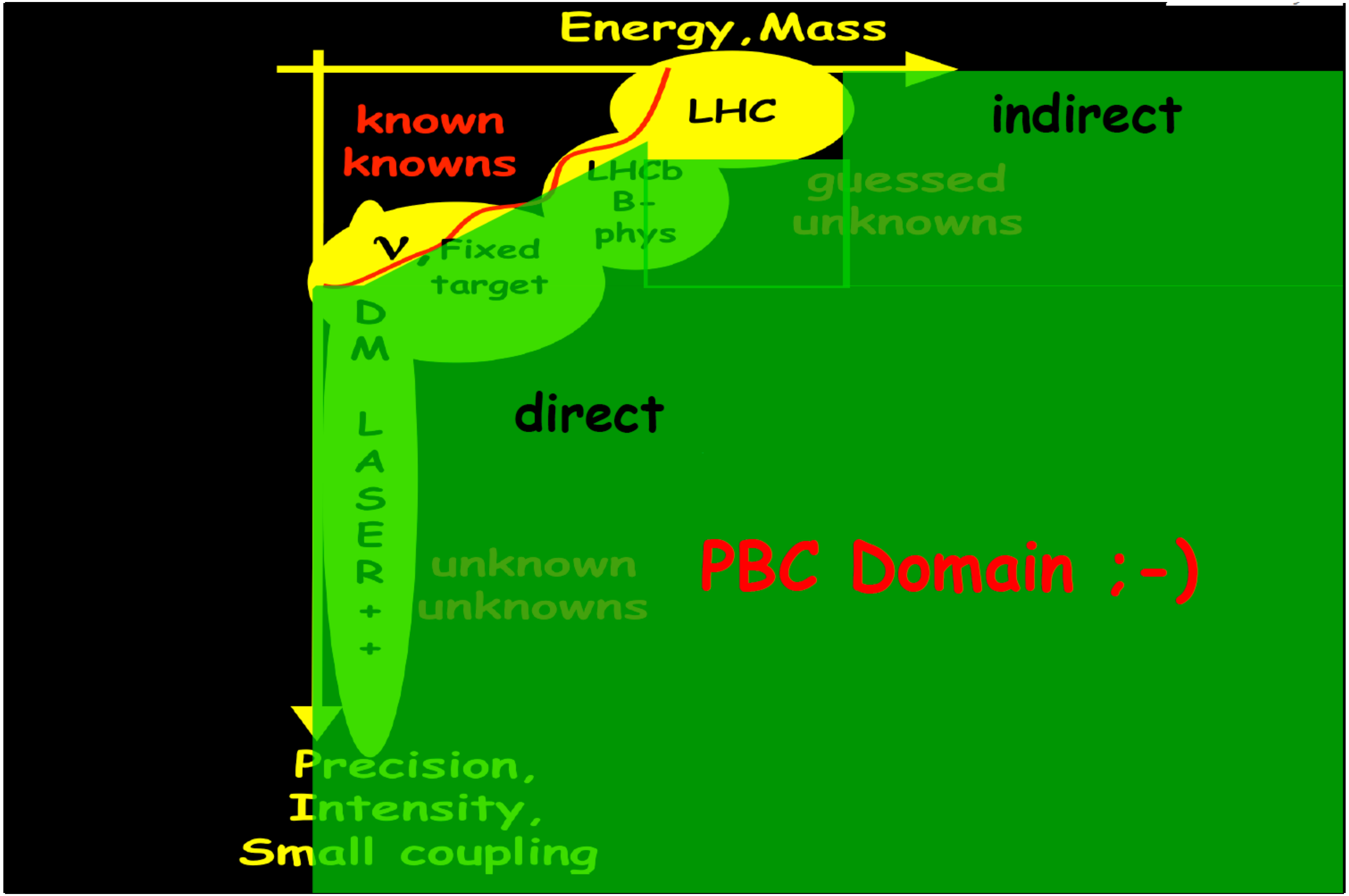
generically small parameters

Strong motivation to search for

- Light Dark Matter (LDM)
- Portals to Hidden Sector (HS) (dark photons, dark scalars)
- Axion Like Particles (ALP)
- Heavy Neutral Leptons (HNL)
- LFV τ decays

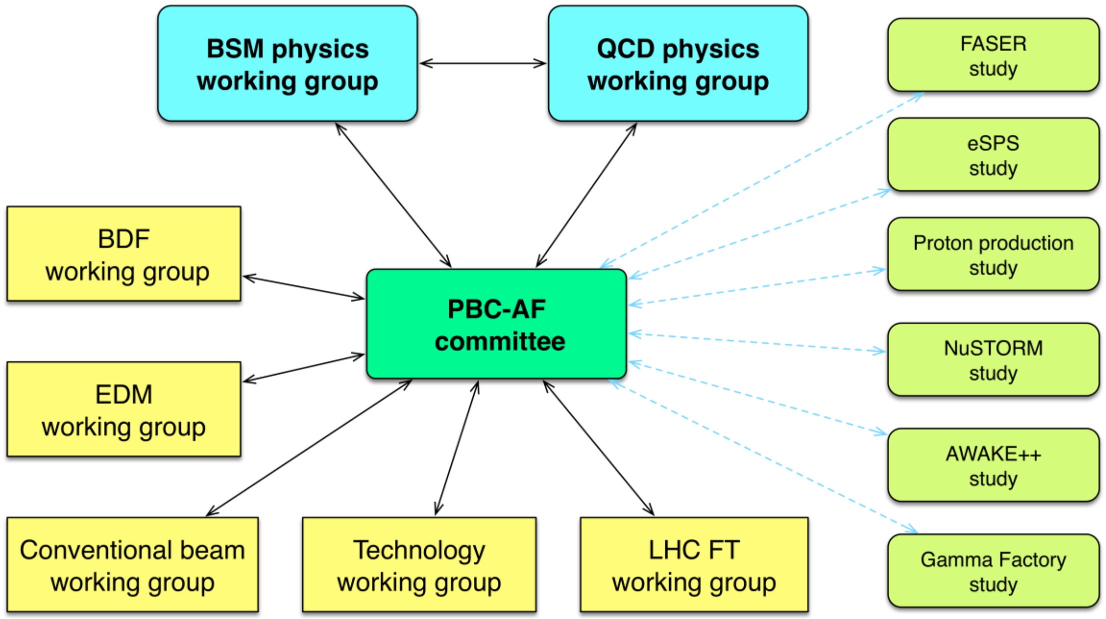
- Many theoretical models (portal models) predict new light particles which can be tested experimentally

- Already active (and continuously growing) set of experiments at intensity frontier at CERN (NA62, NA64, and ~SHiP), in Japan (BELLE-2) and in US (LDMX, APEX, SeaQuest, MiniBoone, HPS, ...)


Energy, Mass
known knowns
LHC
indirect
LHCb B-phys
guessed unknowns
ν, Fixed target
DM LASER++
direct
unknown unknowns
PBC Domain ;-)
Precision, Intensity, Small coupling

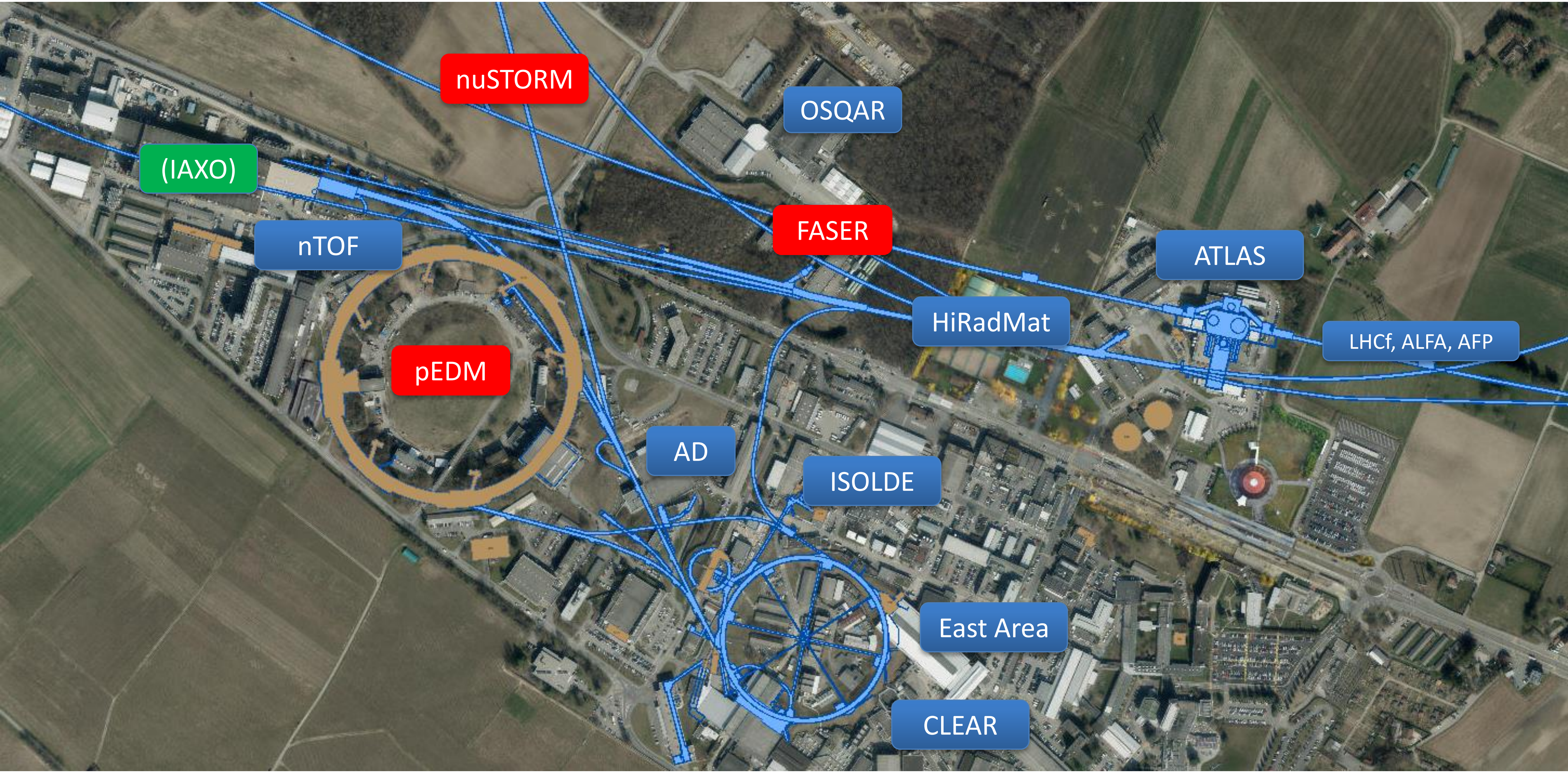
PBC – looking at the options at CERN

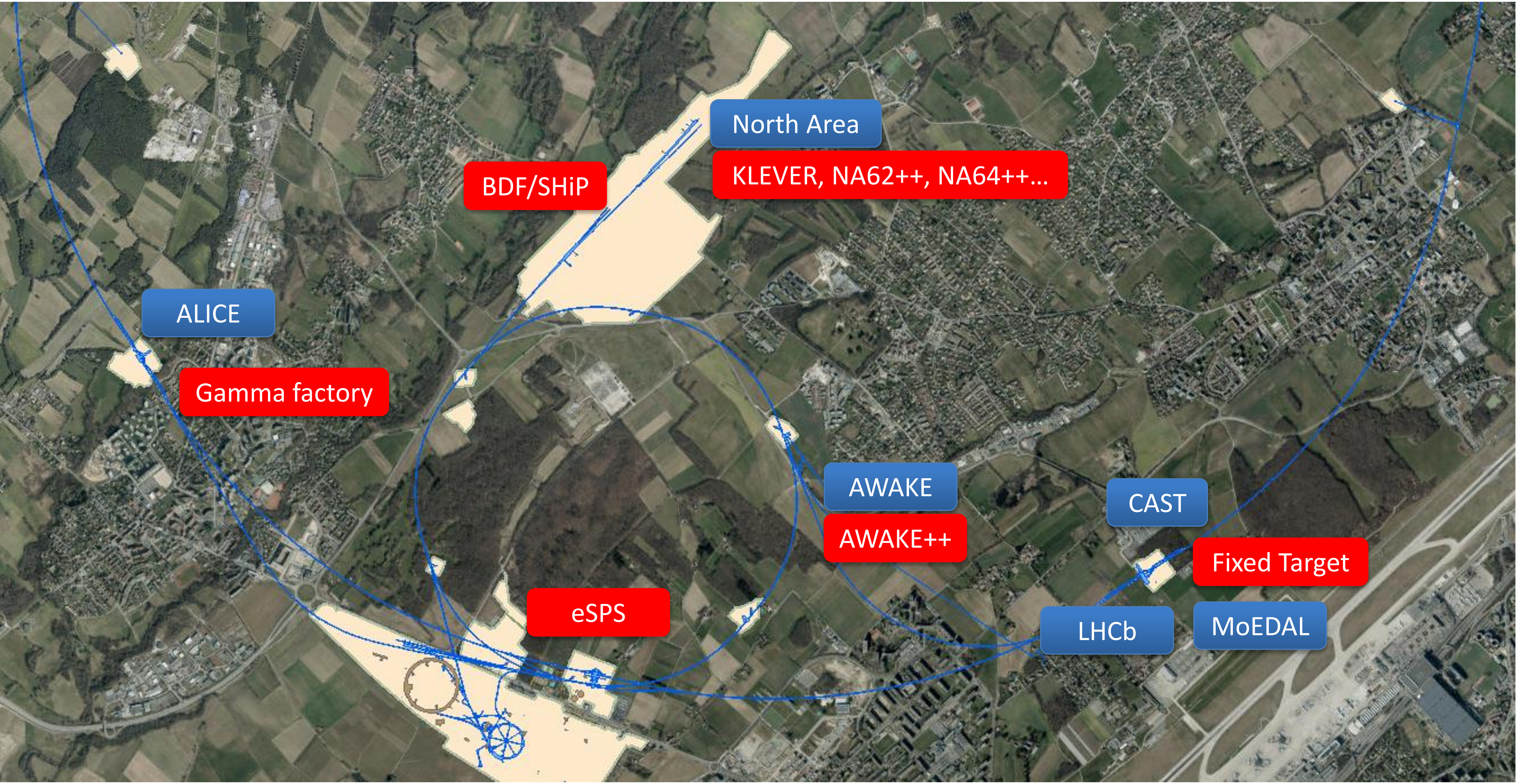
- Dark matter/Beyond Standard Model (BSM)
- QCD
- Other novel uses of the complex



Different levels of maturity!

Study	Aim	Method
BDF/SHiP	Hidden sector	Protons on target
EDM ring	Precision	Proton Electric Dipole Moment
Conv. beams	DM/Precision	North area options (protons)
LHC Fixed target	Precision	Proton on internal target
FASER	DM	LHC proton-proton
eSPS	DM	Electron on target
nuSTORM	Precision	Neutrinos (proton on target)
AWAKE++	DM	Electron on target
Gamma	Various	Partially Stripped Ions in LHC
Technology	DM	Use of CERN technology Axion searches etc.


nuSTORM
OSQAR
(IAXO)
FASER
nTOF
ATLAS
HiRadMat
LHCf, ALFA, AFP
pEDM
AD
ISOLDE
East Area
CLEAR


North Area
KLEVER, NA62++, NA64++...
BDF/SHiP
ALICE
Gamma factory
AWAKE
AWAKE++
CAST
Fixed Target
eSPS
LHCb
MoEDAL

Beam Dump Facility

Very well covered this week by:

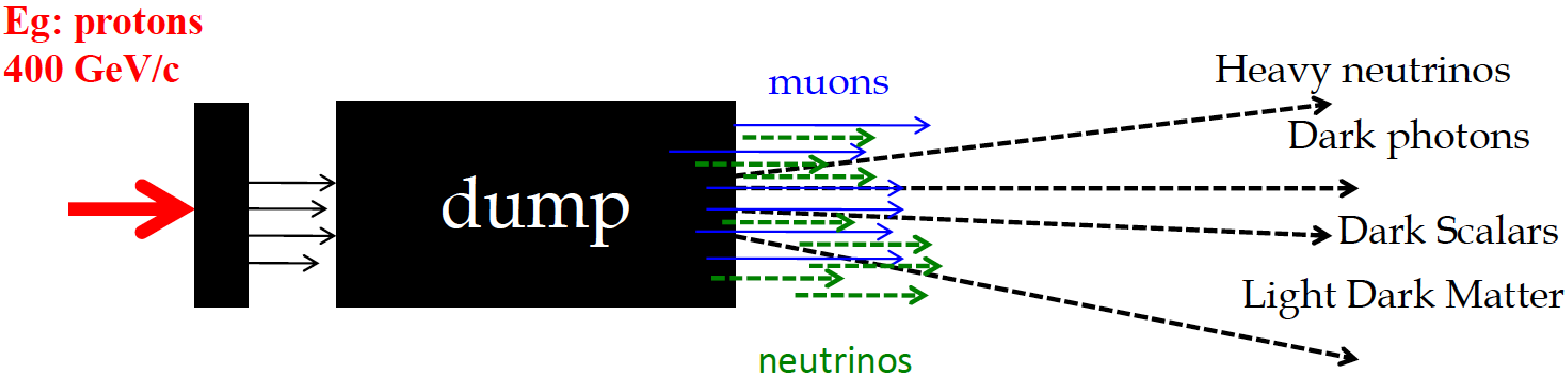
- **Edmundo Lopez Sola,** *Beam Dump Facility target: design status, beam tests in 2018 and material studies*

- **Heinz Vincke,** *Beam Dump Facility (BDF) at CERN radiological and environmental assessment*

- **Keith Kershaw,** *Preliminary design study of the integration and remote handling processes for the Beam Dump Facility Target Complex*

Special mention to Marco Calviani!

Beam dump experiment

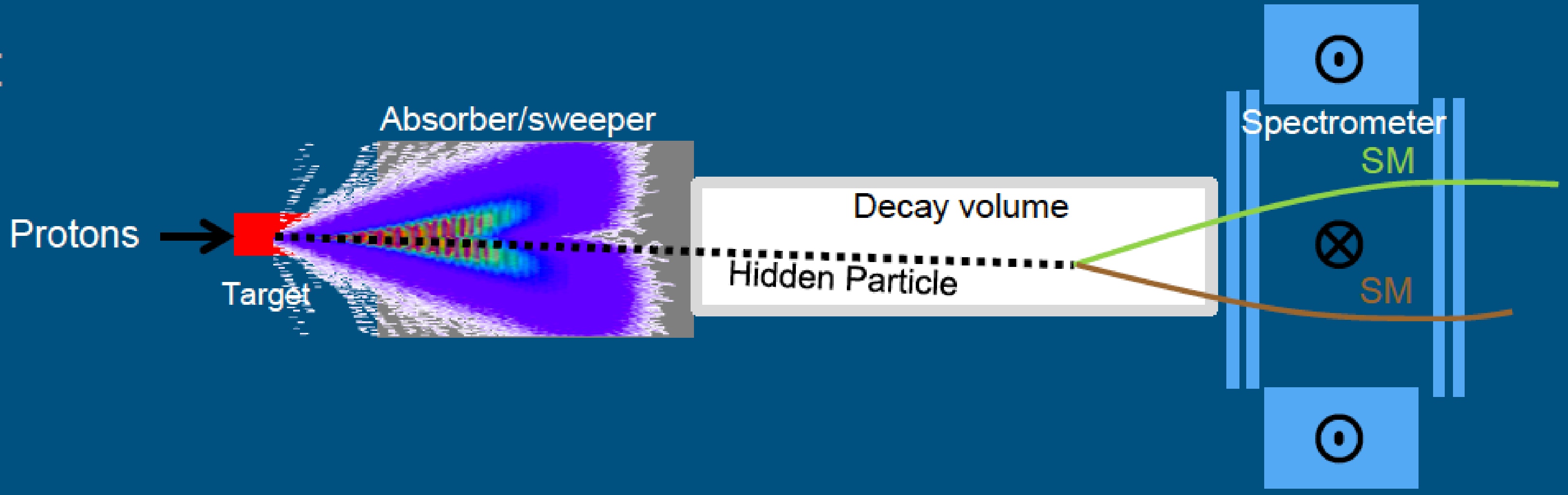


Any kind of feebly-interacting
long-lived particle or LDM
(put here your favored model);

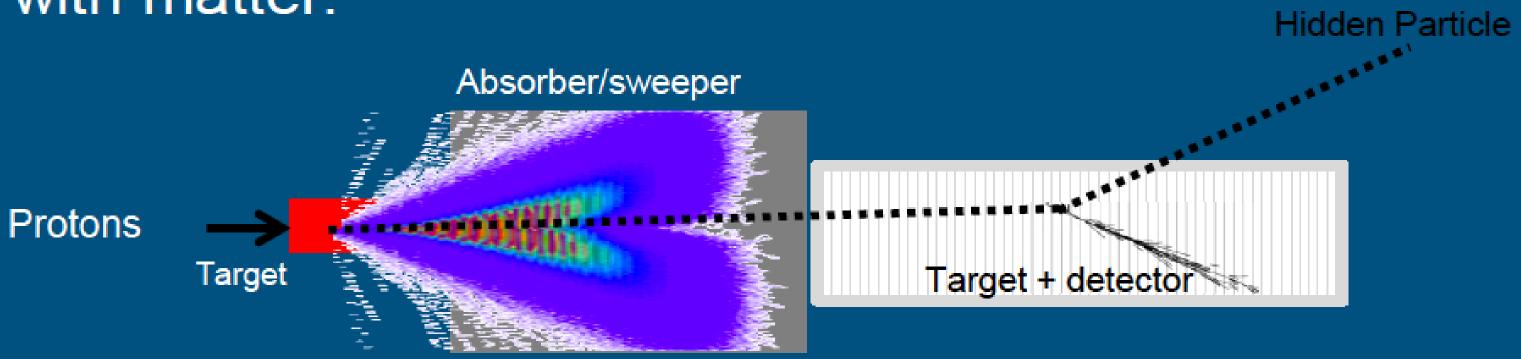
Recipe for discovery and drivers of the layout of the facility:

1. Maximum number of high energy protons
2. Heavy target
3. Deflection of ordinary collision debris particles
4. Large detector volume

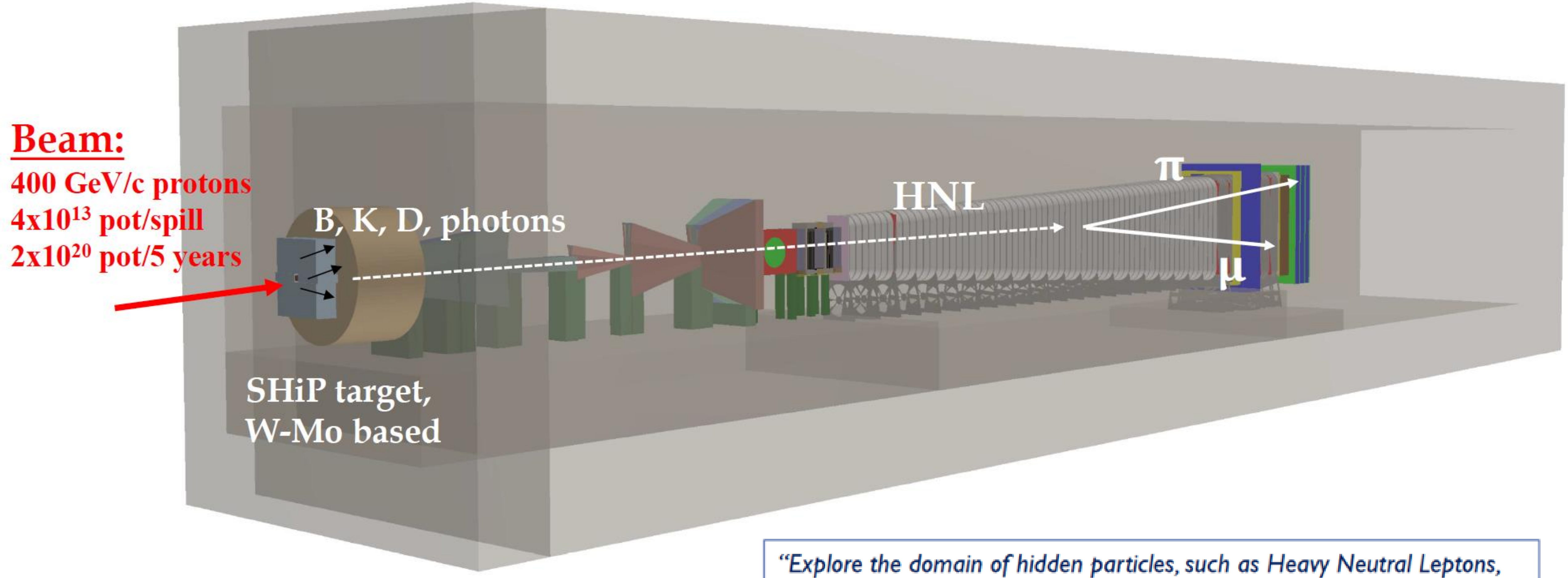
Detection by Decay:



Detection by interaction with matter:



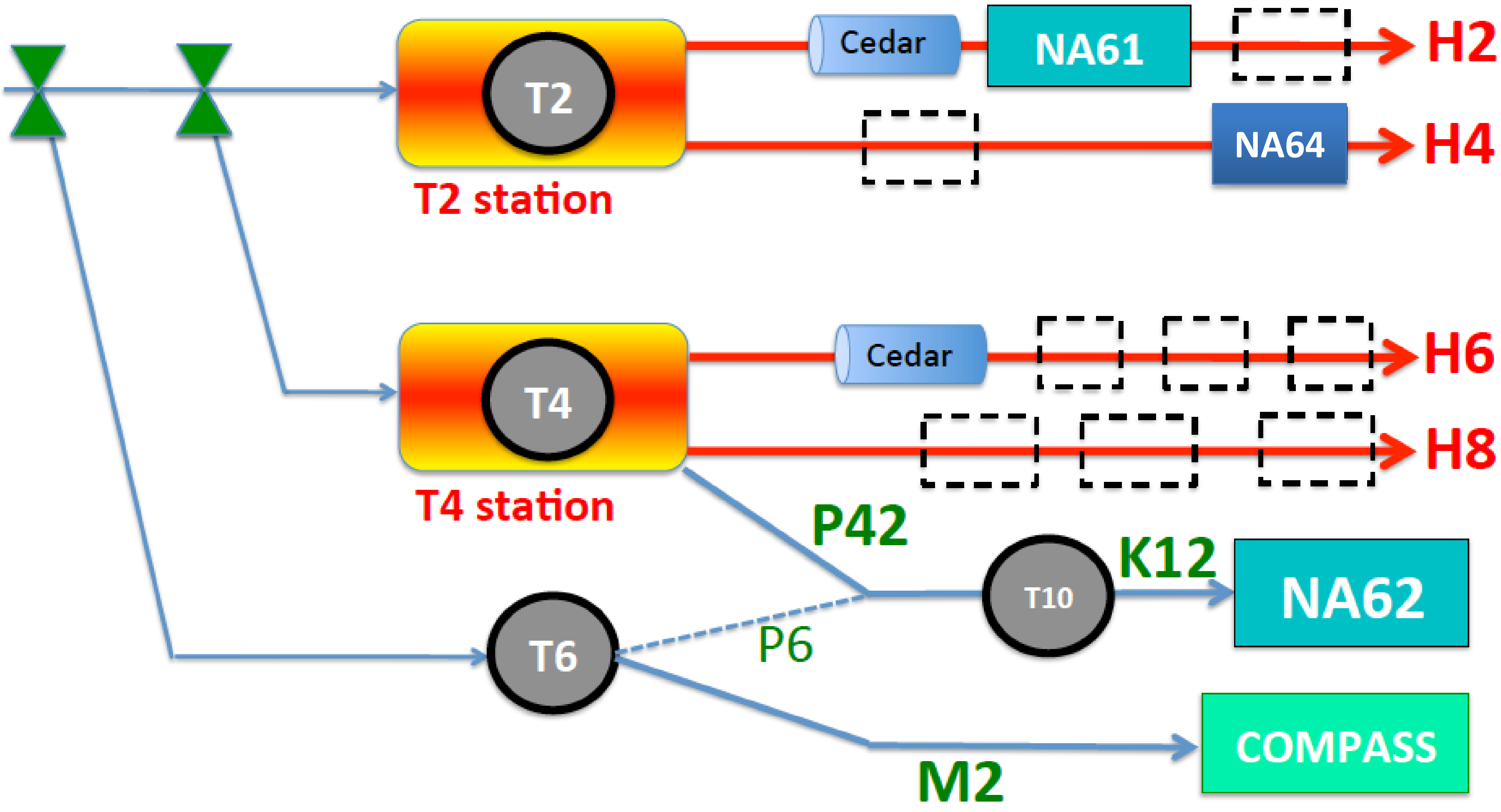
Search for Hidden Particles



"Explore the domain of hidden particles, such as Heavy Neutral Leptons, dark photons, supersymmetric particles…"

THE SPS NORTH AREA

Slow extraction, 400 GeV/c



Conventional beams at the North Area

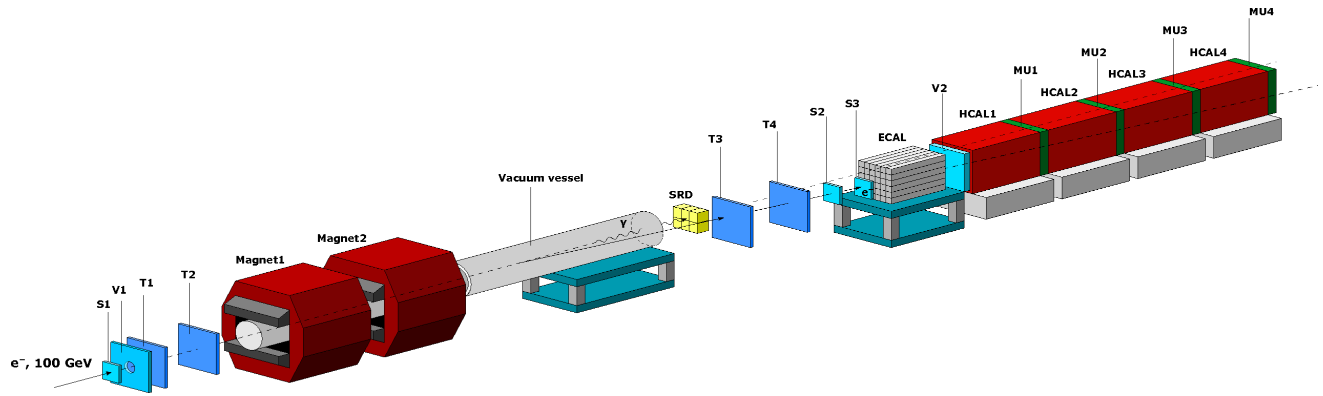
Enthusiastic set of proposals from existing and new clients

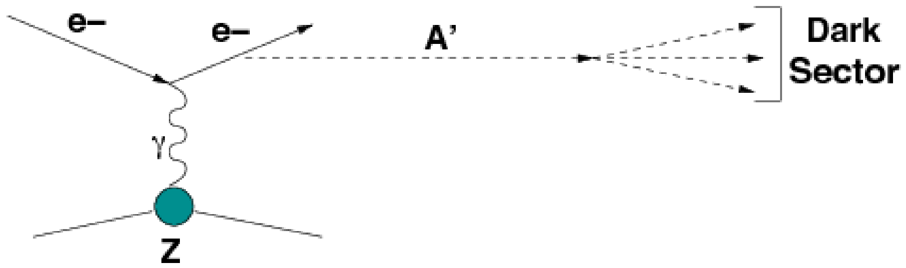
Perform **pre-proposal studies** focusing on those leading to a possible short and medium time-scale implementation, as well as on those which seem to be the most advanced and competitive.

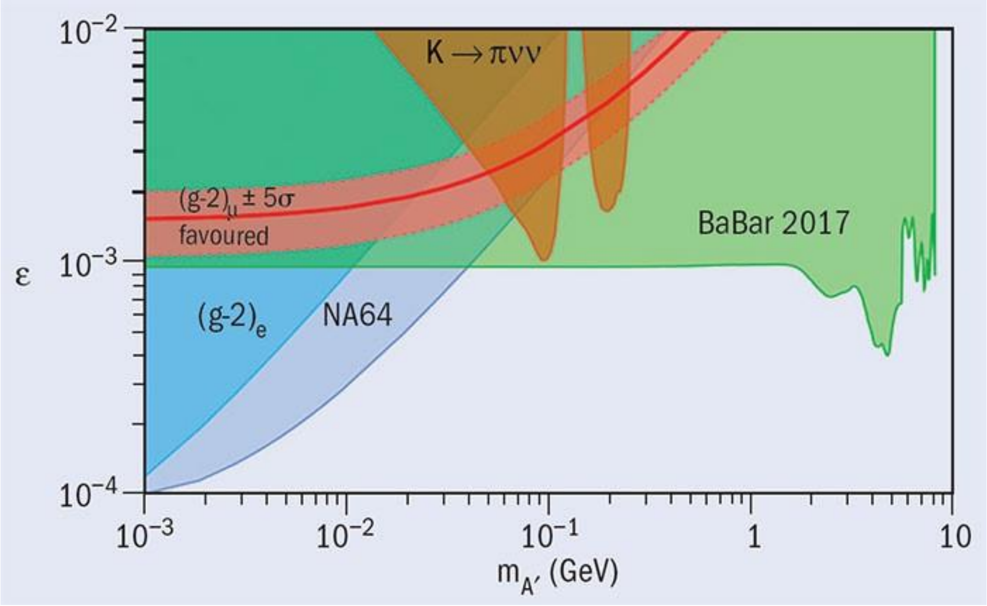
NA62++	Proposal to operate in beam-dump mode for dark particles searches
NA64++	High intensity electron, muon and hadron beams for dark particles searches
KLEVER	High intensity K_L beam (high flux, pencil beam, new target) for rare decays
COMPASS++	RF separated beams for hadron structure and spectroscopy
MUonE	150 GeV muon beams for high precision hadron vacuum polarisation for g(mu)
DIRAC++	High statistic mesonic atoms
NA60++	Heavy ion beams for dimuon physics
NA61++	Higher intensity ion beam for charm studies

Lau Gatignon

Search for dark sectors in missing energy events



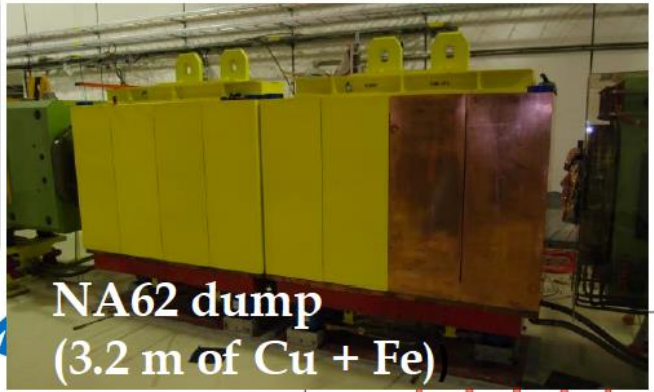


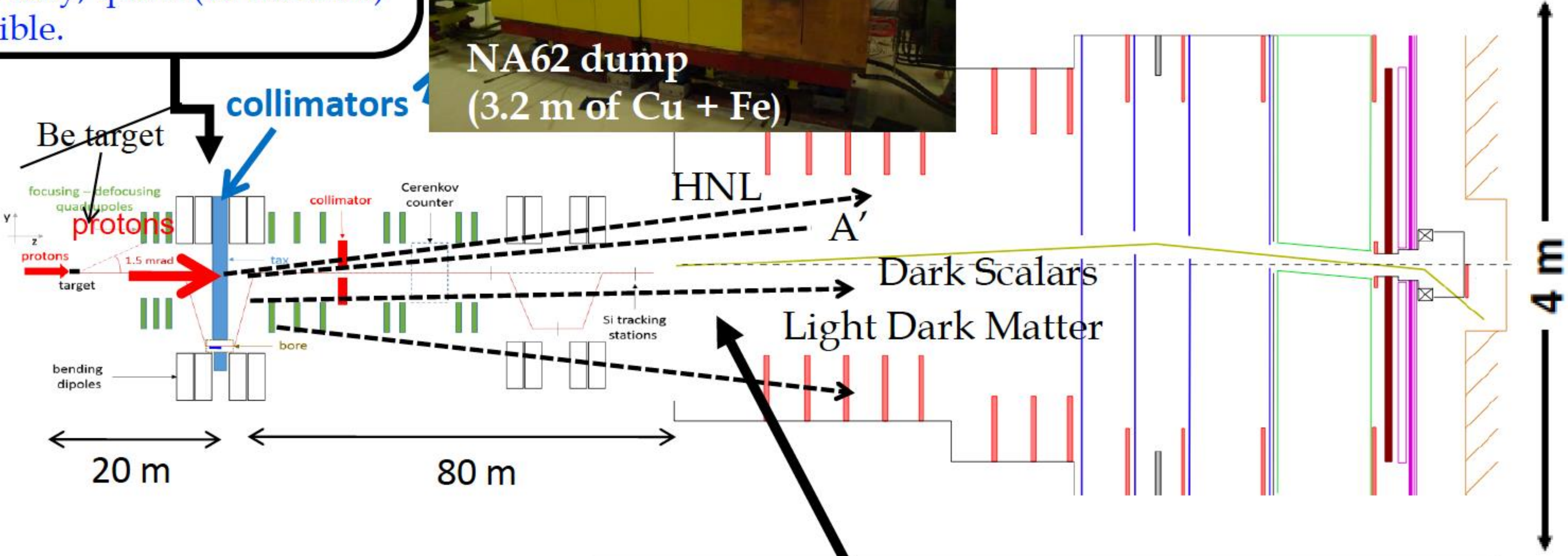


NA62 in "dump" operation mode

In dump mode the target can be moved away from the beam and the beam let impinging on the copper. Hence: the collimators can act as a dump.

→ this operation is easy, quick (15 minutes) and fully reversible.



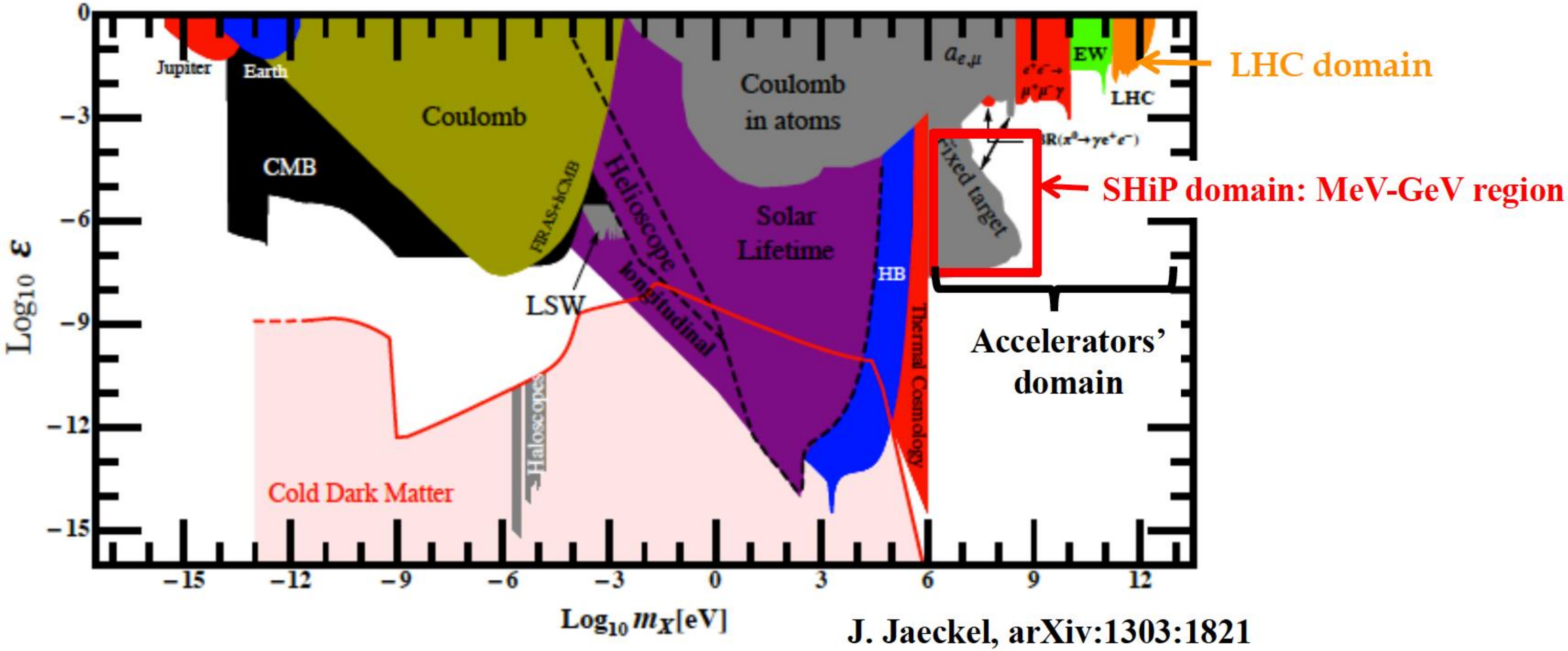


Heavy Neutrinos, Dark Photons, Dark scalars, and ALPS can be originated by charm, beauty and photons produced in the interaction of protons with the dump.

G. Lanfranchi

.... A walk through the orders of magnitude....

kinetic mixing of a dark photon-ordinary photon



J. Jaeckel, arXiv:1303:1821

MeV-GeV region is special: hidden particles in this range could be DM mediators if DM is lighter than a WIMP

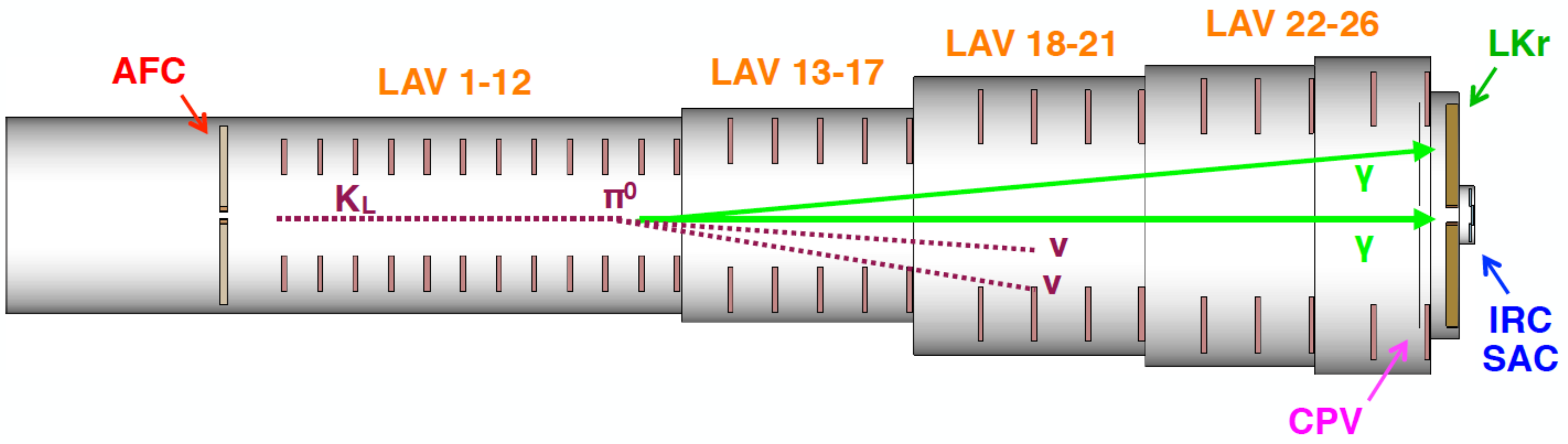
$K \to \pi\nu\nu$ and new physics

KLEVER

Null NP results from direct searches at LHC so far - but NP may simply occur at a higher mass scale

Indirect probes to explore high mass scales is even more interesting

$K \to \pi\nu\nu$ is uniquely sensitive to high mass scales ~O(10^3 TeV)



Primary Beam:

400 GeV/c p on 400 mm Be target with production at 2.4 mrad to optimize (K_L in FV)/n

Required total proton flux:
- 5 × 10^{19} pot
- 10^{19} pot/year (= 100 eff. days)
- E.g.: 2 × 10^{13} ppp/16.8 s
- uniform spill structure

upgrades to target area and transfer lines

3 × 10^{13} K_L decay in fiducial volume (FV) needed for 100 signal events

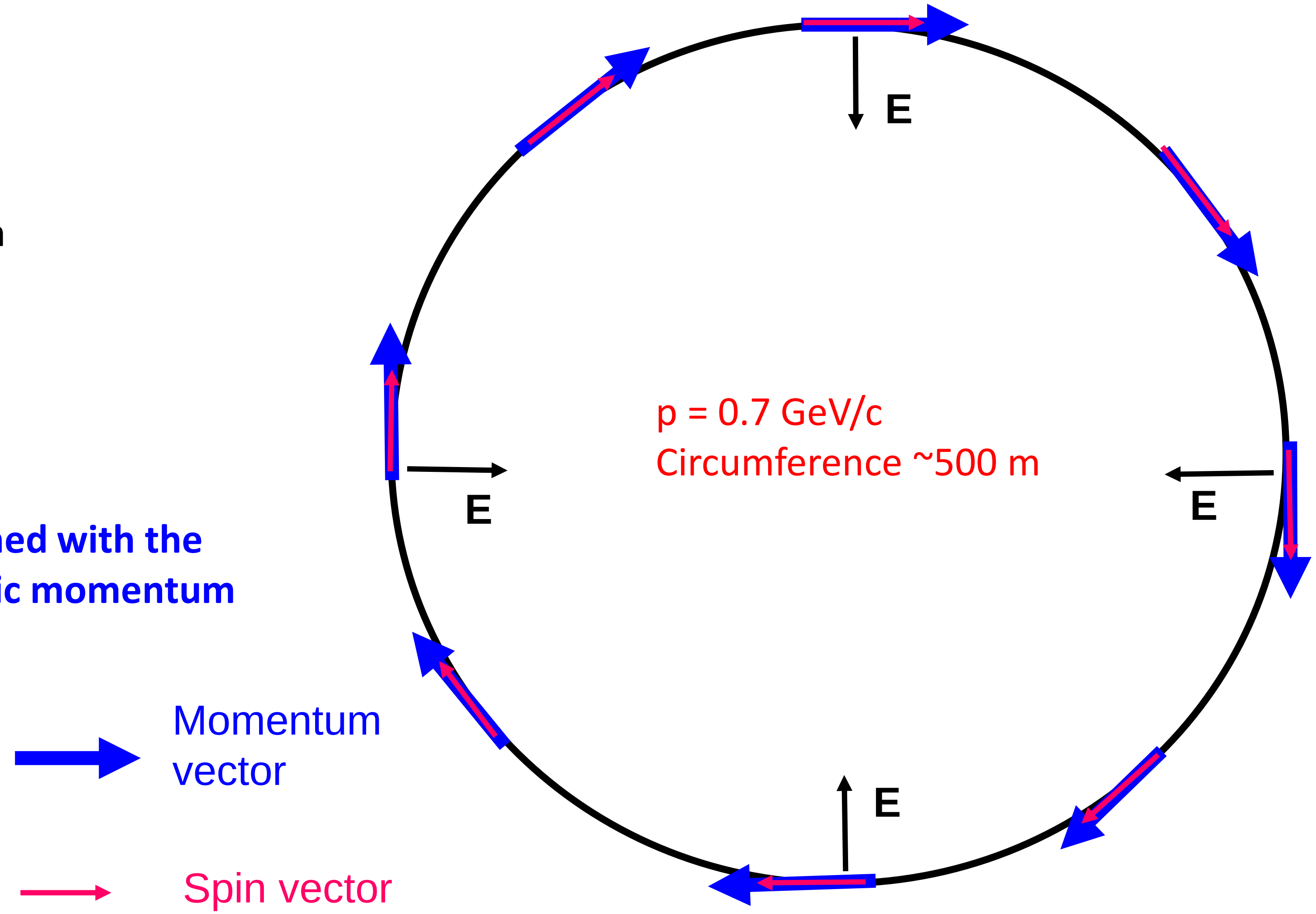
Proton Electric Dipole Moment

Neutron EDM
$|d_n| < 3.0\times10^{-26}\ e\cdot\text{cm}$

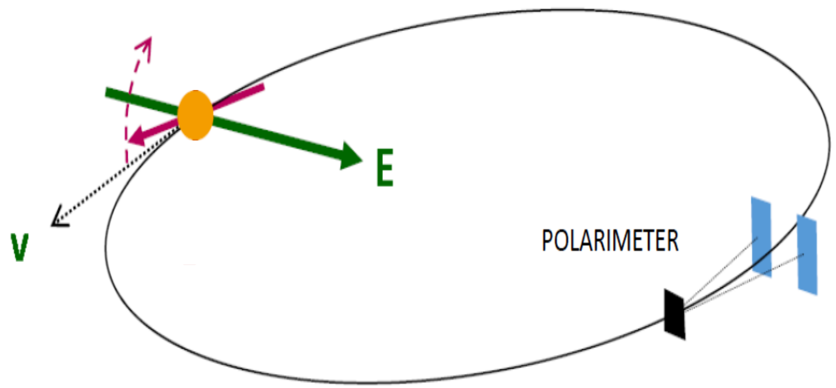
Proton EDM
$|d_p| < 7.9\times10^{-25}\ e\cdot\text{cm}$

Standard model: ~$10^{-32}\ e\cdot\text{cm}$

ALL-ELECTRIC ring: spin is aligned with the momentum vector at the magic momentum



Very challenging!



Imagine measuring the build up of vertical polarization component over about 1000 s. And then repeating many, many times.

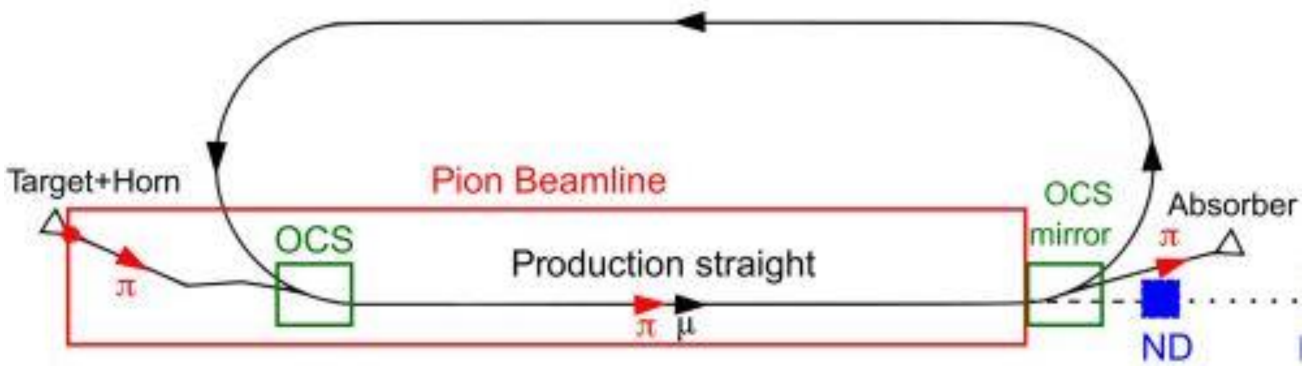
Well developed proposal but…

10 aT level average radial B-field and 8 MV/m radial E-field lead to comparable vertical spin precessions

atto = 10^{-18}

nuSTORM

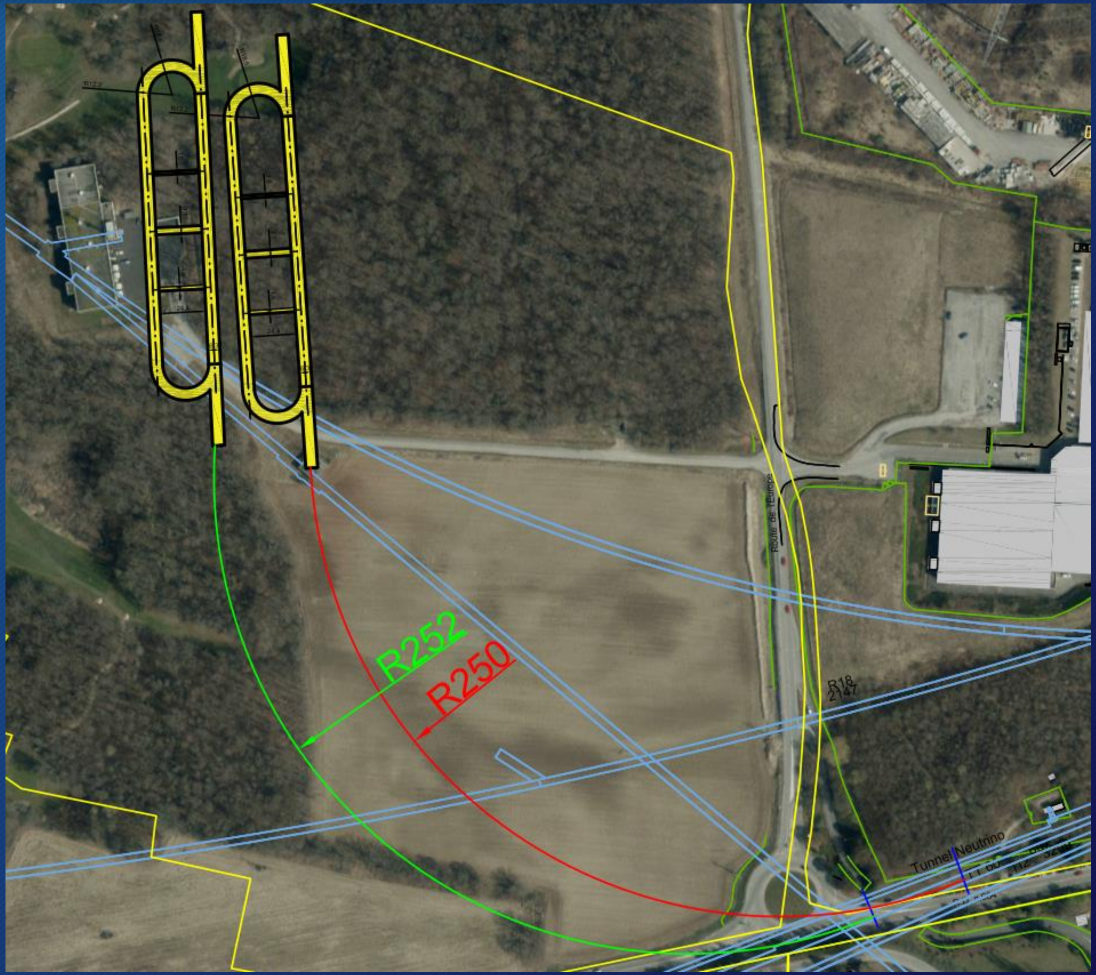
- The potential for delivering a neutrino beam from a muon storage ring have well developed by the nuSTORM collaboration.
- An in-depth study was performed for a possible implementation at Fermilab
- **Sketching** possible implementation at CERN using 100 GeV/c protons from SPS



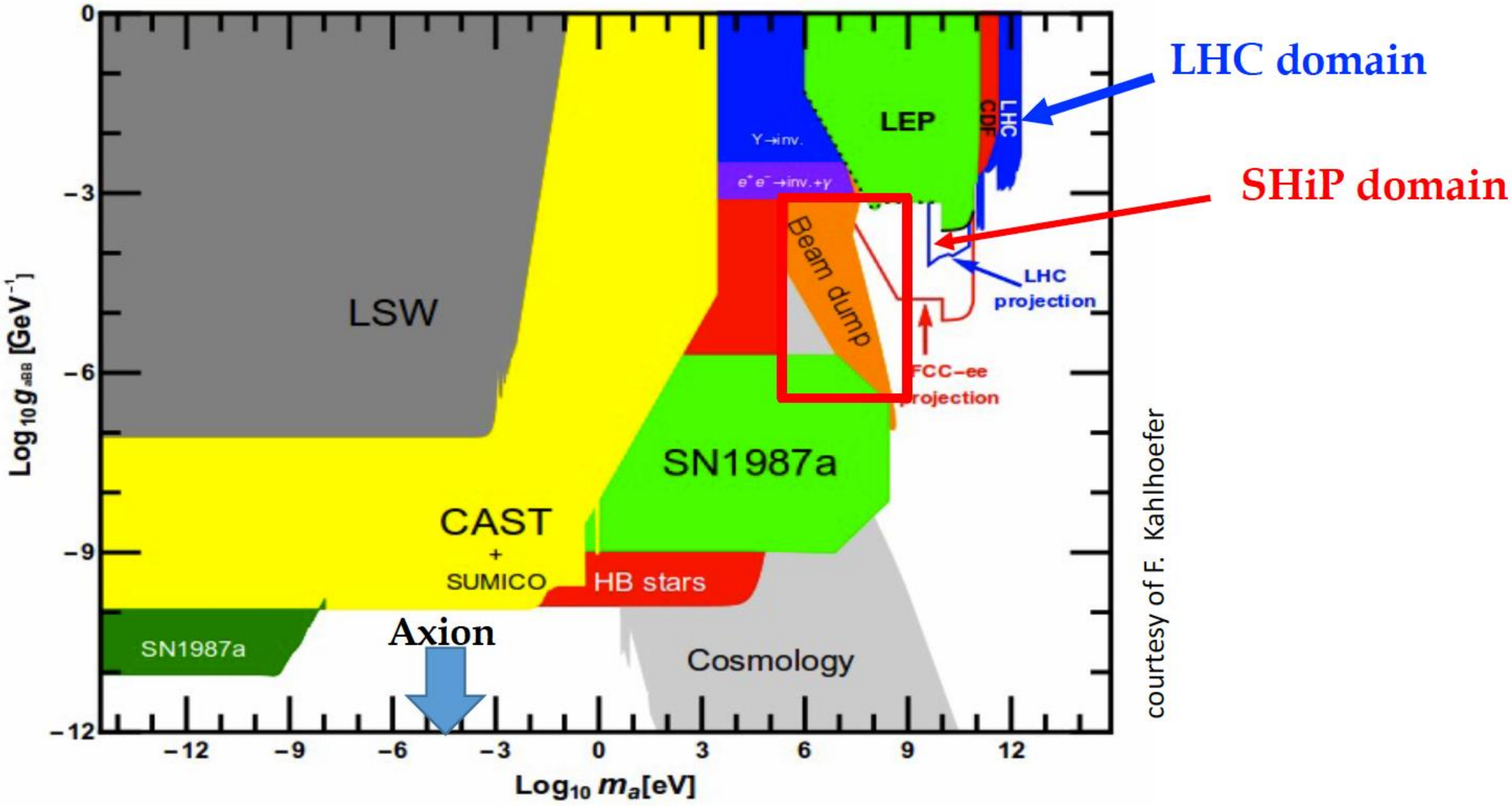
Momentum	100 GeV/c
Total POT	2.3e20 in 5 years
Proton per pulse	4e13
Nominal power	156 kW

Civil Engineering – Options 2-3 Comparison

- ≈250m Radii for bending of extract tunnels
- Varying extract points
- Separation from existing tunnels
- Proximity of existing structures
- Proximity to golf course
- CERN land (yellow outline)

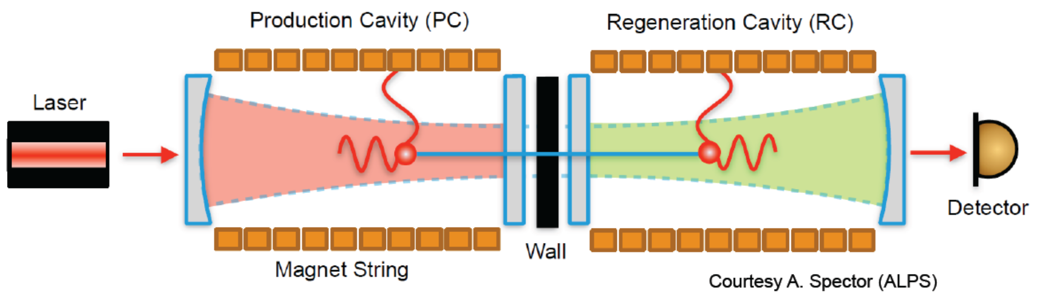


…A walk through the orders of magnitude…
Axion and Axion-Like Particles

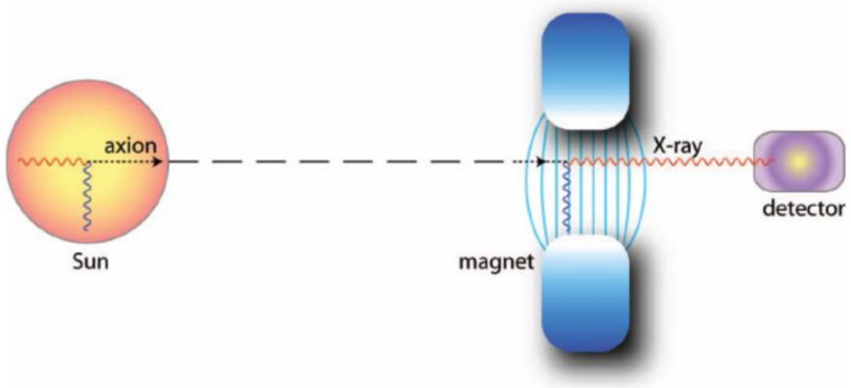


- The axion was introduced to solve the strong CP problem in QCD: m~ 10^{-5} eV
- Other (pseudo)-scalar particles can feature very similarly to the axion but with larger mass: ALPS

- **Purely laboratory experiments**
  - "light-shining-through-walls" ⇒ optical photons

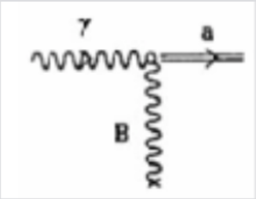


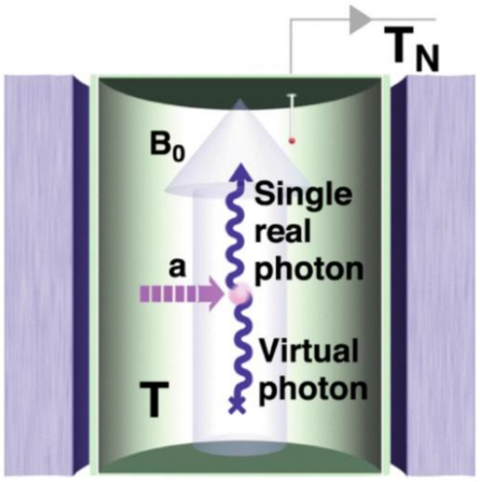
- **Helioscopes**
  - WISPs emitted by the sun ⇒ X-rays



- **Haloscopes**
  - Looking for axions in Milky Way halo (DM) ⇒ μ-waves

Primakoff effect





Technology working group

- Helioscopes (IAXO)
- Light shining through walls (LSW)
- Haloscopes
- Magnetic birefringence of vacuum
- Fabry-Perots - density-dependent fields
- WIMP Dark Matter (Darkside)

$\otimes$

- Magnets
- Optics/optics sensing
- RF cavities
- Cryogenics
- Vacuum

Table X.1 List of PBC Initiatives that require CERN's Magnet Support and requesting CERN siting.

#	Initiative Name	CERN siting proposed	CERN requested magnet support
1.	(Baby)IAXO, solar Axion search	Eventually	Magnet design, engineering and construction support
2.	Haloscope, Axion search (using Hybrid Magnet Grenoble)	No, Grenoble	Detector magnets expertise
3.	LSW-OSQUAR+ , Axion search	Yes, i.e. B180	Supply of 10+10 spare 8T LHC Dipole Magnets, Cryogenics and Powering
4.	LSW-ALPS-III, Axion/WISP search	Yes	Some 20 units 15-16T FCC type Dipole Magnets, add on to preseries
5.	LSW-STAX, Axion search	Yes	2 units 11 T short model Dipole Magnets in 2 cryostats, Cryogenics and Powering
6.	PVLAS	Yes	1 high field LHC+ Dipole Magnet, Cryogenics and Powering

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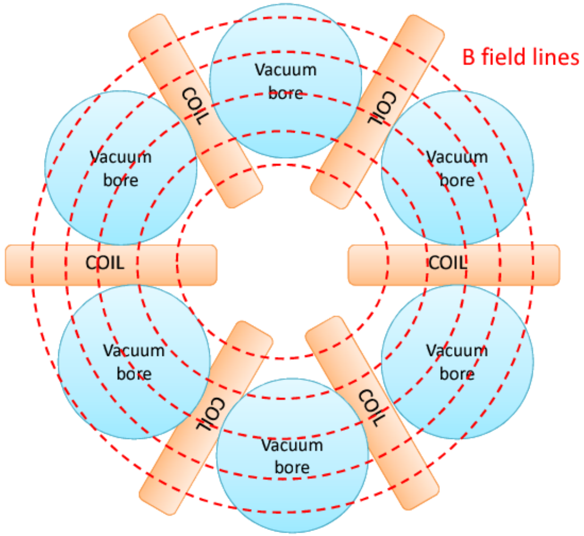
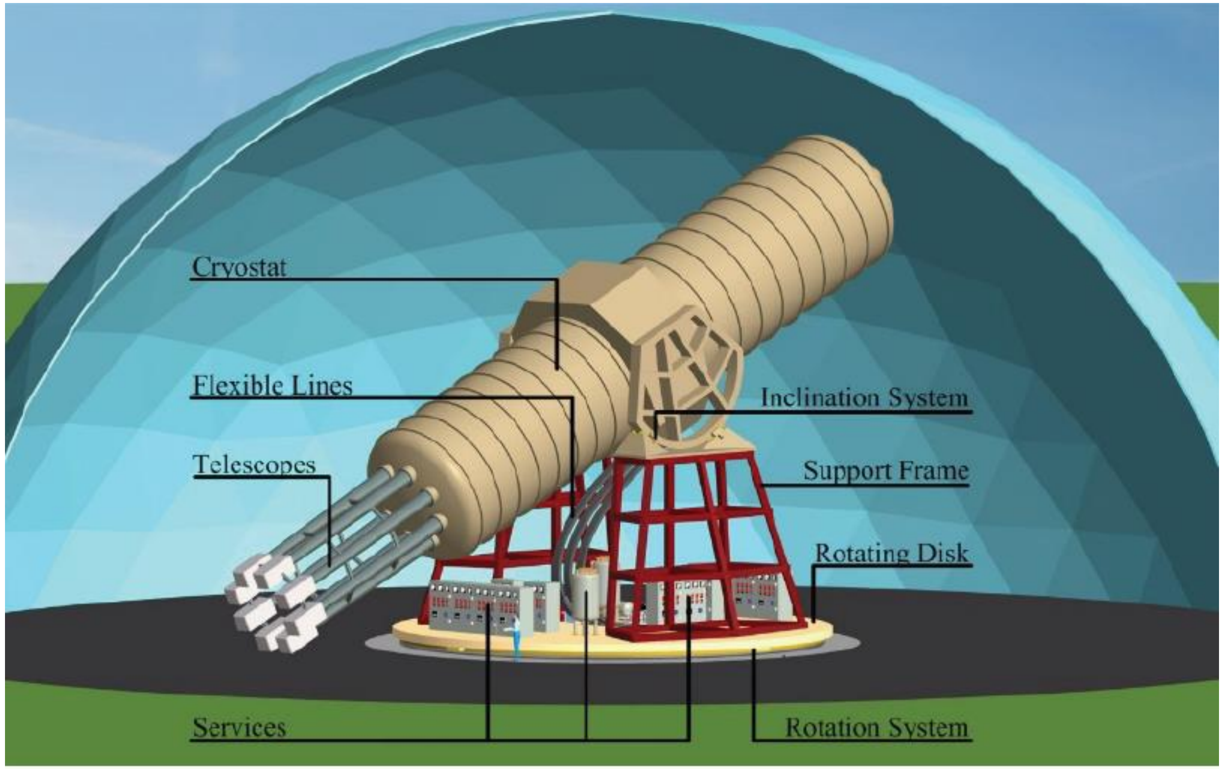
Helioscopes

- CERN Axion Solar Telescope (CAST) operational
- CERN actively involved in magnet R&D for IAXO and a proposed precursor BabyIAXO



IAXO

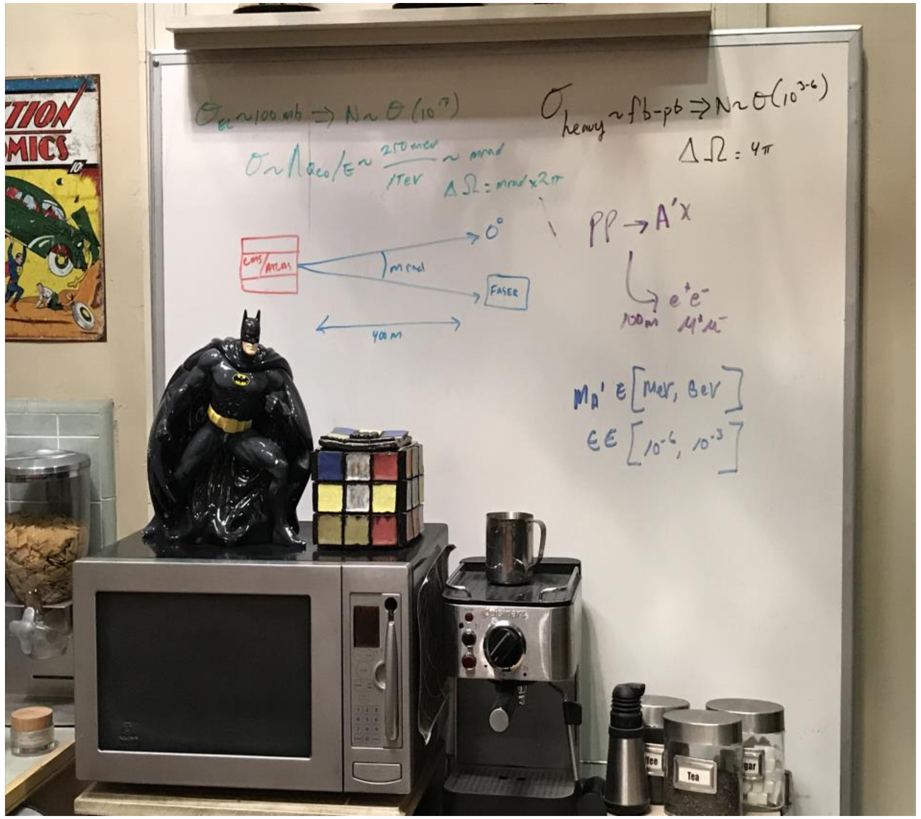
The International Axion Observatory



Possible siting at DESY

FASER

- New ideas extend the discovery prospects of the LHC program for the HL-LHC era
- And they have already attracted the attention of two of the world’s best known physicists!



Incoming

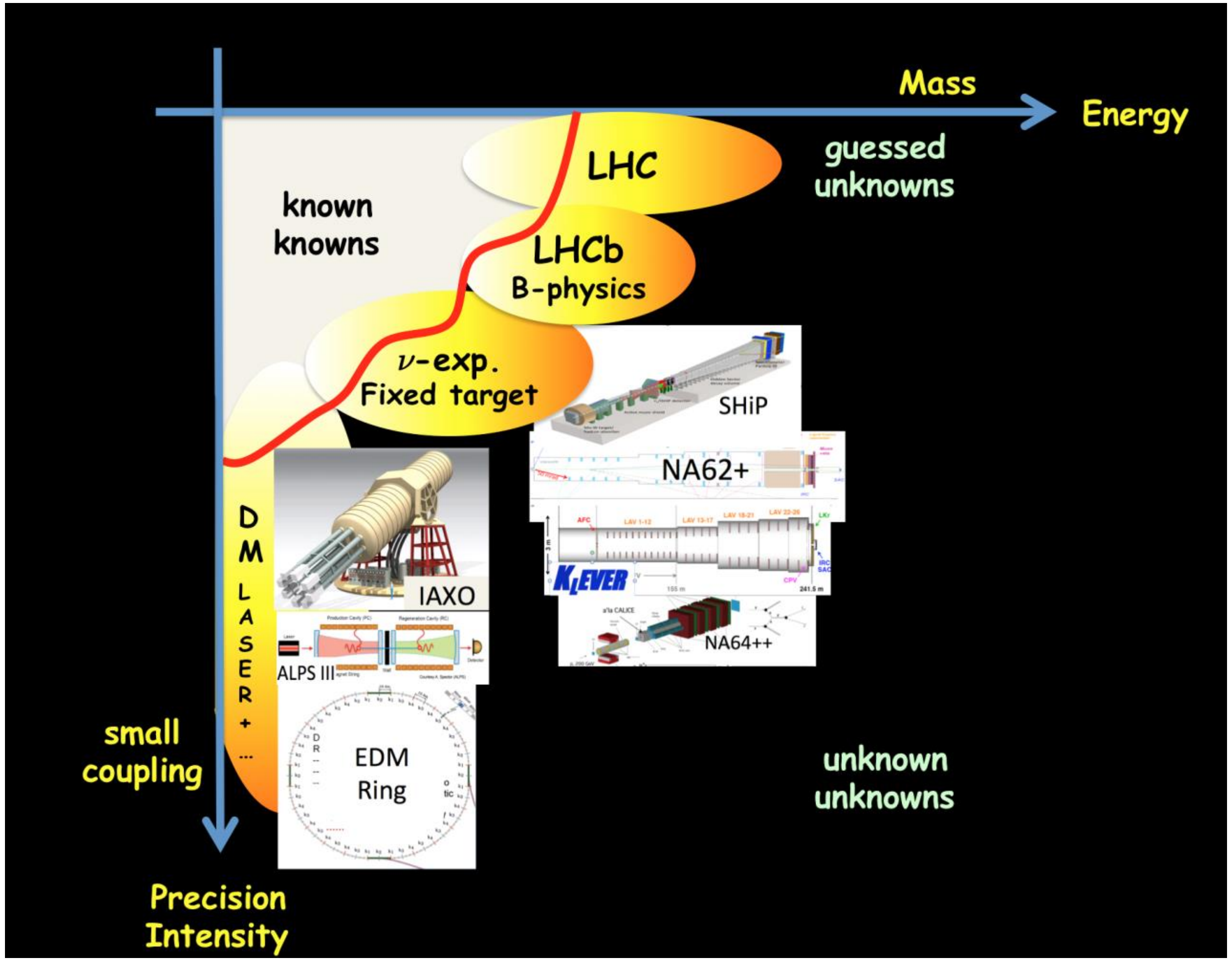
- Preparing documentation as in input to the update of the European Strategy for particle physics
  - Overview document: BSM part
    - Overall physics case/worldwide context
    - Sensitivity in simplistic models for comparison
  - Individual documents for each proposal
    - Detailed and broad physics case for each experiment
    - Precise sensitivity studies
    - Technical design

Conclusions 1/2

- **High energy**: search for new heavy particles with strong couplings.
  - LHC++
- **High intensity**: indirect search for new heavy particles with small couplings leading to deviations from the SM through the loops:
  - LHCb, NA62, BELLE, flavour physics experiments,...
- **High intensity**: search for new light particles with small couplings:
  - Heavy neutral leptons, dark photons, Axion Like Particles, ... SHiP, NA62, NA64...

- CERN is a good place to search for Hidden Sector at SPS North Area with SHiP and NA62 in < O(10) GeV range

Conclusions 2/2



Besides the more traditional fixed target we're also exploring:

- Electrons from the SPS
- Long lived particles (LLP) from the LHC
- Proton Electric Dipole Moment Storage ring
- Gamma rays from LHC partially stripped ions
- Neutrinos from a muon storage ring
- Non-accelerator options such IAXO

Interesting times!